Illinois Agricultural Pesticides Conference '88 Fortieth Spray School

Summaries of Presentations
January 5, 6, & 7, 1988
Urbana, Illinois

Cooperative Extension Service
University of Illinois
at Urbana-Champaign
College of Agriculture
in Cooperation with
the Illinois Natural History Survey

Cooperative Extension Service
University of Illinois at Urbana-Champaign

The Illinois Agricultural Pesticides Conference is an annual program presented primarily for commercial pesticide applicators and dealers, but it is open to anyone in agriculture who has an interest in using pesticides in a crop pest management program. The conference promotes the proper, timely, and wise use of pesticides within an integrated crop management system. The program is presented by the University of Illinois at Urbana-Champaign, College of Agriculture, the Cooperative Extension Service, and the Illinois Natural History Survey.

We gratefully acknowledge the assistance of the Illinois Department of Agriculture, the Illinois Fertilizer and Chemical Association, and the Illinois Agricultural Aviation Association in planning and staging the program.

This publication contains summaries of the presentations made at the Illinois Agricultural Pesticides Conference on the dates indicated on the front cover. Many of these summaries are research reports that are intended to bring you the latest research information about agricultural pest control. Some of the chemicals discussed in the summaries are not registered for use by the public and thus are not intended as recommendations. The Illinois Pest Control Handbook contains suggestions for using registered pesticides. The use of trade names does not imply or constitute endorsement by the University of Illinois nor imply discrimination against other products.

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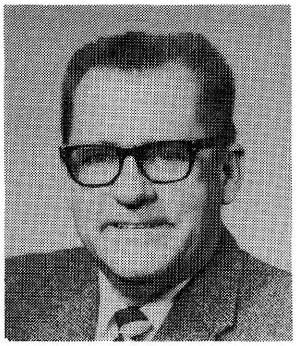
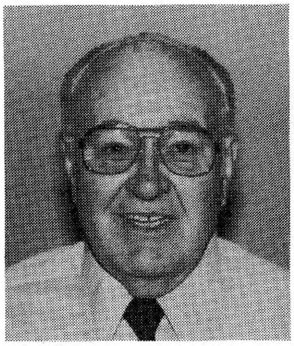
The 40th Illinois Custom Spray Operators Training School Is Dedicated to

The Patriarchs



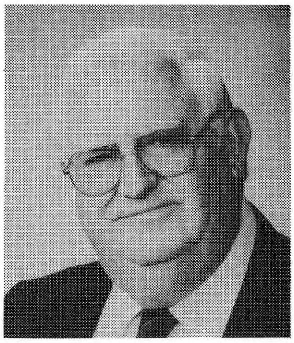
H.B. "Pete" Petty



Lillard Hedden

Robert Rider

John Pool



Dean Roy

Walter "Scotty" Scott

These six gentlemen, led by Pete Petty, the founder of the "Spray School," have attended this conference for 38 to 40 years. The program's original objectives and content, which they initiated, have remained as the foundation for all 40 schools. The unfaltering support and commitment of these men have helped legitimize the business of agricultural pesticide application and sales--for this, we owe them our sincere gratitude.

THANK YOU, AND BEST WISHES FOR THE FUTURE

H.B. "Pete" Petty. Pete began work at the Illinois Natural History Survey in 1939 as a research associate. In 1941, he became the first Extension entomologist in Illinois and remained as such until 1973, when he became Assistant Director, Agriculture, for the Illinois Cooperative Extension Service. Pete retired from Extension in 1979, and was honored as a Professor Emeritus of Agricultural Entomology. His fondest (?) "Spray School" memory was the ice storm that hit in 1967. The electricity went off and many attending the conference could not get their cars started. Pete called a service station to get jumper cables to start the cars and rented a bus to get everyone to the school on time. The "Spray School" has always been noted for bad weather, but the program must go on!

Lillard Hedden. Lillard started Hedden's Flying Service in 1947. Since that time, he has flown nearly 20,000 hours, used nearly one million miles of trucking support, and handled hundreds of thousands of gallons and pounds of almost every kind of agricultural chemical made. Through all of this, Lillard has flown for 37 years without an injury to anyone! He retired from the agricultural aviation business in 1984, but he continues to attend the "Spray School" annually and has done so for 40 years since its inception.

Robert Rider. In 1945, Bob began work in the agricultural pesticides business as a salesman for Thompson-Hayward; he works for the same company today. During his tenure with Thompson-Hayward, Bob has also been a branch manager, but he's now back to his old "habits" as a salesman again. Bob attended the first "Spray School" in 1949, and has attended every year since. He believes that the program has held onto and maintained its character since the beginning.

John Pool. John has attended the "Spray School" for 39 years, missing only the 1966 school when he was touring South Africa. In 1949, he started working in the pesticides business as a representative for a distributor of agricultural chemicals. In 1961, he formed his own company, John W. Pool Co., to sell retail to customers who applied their own products. He also did some custom application for 15 years and continued to farm his own land. In 1984, John's son, Greg, took over the farming operation and the agricultural chemical business, but John remains active in the business. The high point of his winter is the "Spray School," which he attends to keep informed, renew old acquaintances, and make new friends.

Dean Roy. Dean came to the first "Spray School" in 1949 as an employee of Dow Chemical and has attended 39 of the 40 schools. He worked for Dow until 1958, Associated Sales from 1958 to 1961, and Thompson-Hayward from 1961 to 1969. In 1969, Dean began working for Cole Chemical (now Cole/Grower Division of United Ag Products) and has remained with the company to this day. One of Dean's special honors was when the Midwest Agricultural Chemicals Association established the Dean Roy Salesmanship Award, an award given to an MACA member each year for meritorious service to the association. Dean says that Illinois and the "Spray School" have always been a centering force for him throughout his career.

Walter "Scotty" Scott. Scotty started work for the University of Illinois in 1946 as an Assistant Professor of Agronomy. He became a full Professor of Extension Agronomy in 1960, and has spent many hours on the road travelling to meetings with Pete and other university Extension specialists. In 1981, he retired from the University and was honored as Professor Emeritus of Agronomy. He is currently the Executive Secretary-Treasurer for the Illinois Seed Dealers Association. Scotty remembers when Pete Petty first mentioned organizing a school to educate people becoming involved in the new business of agricultural pesticide sales and application. He must have bought the idea because he has attended 38 of the 40 schools.

Contents

PROGRAM

GENERAL INFORMATION

SUMMARIES OF PRESENTATIONS

ILLINOIS AGRICULTURAL PESTICIDES CONFERENCE '88

40th Illinois Spray School

The **Illinois Agricultural Pesticides Conference** is an educational program sponsored by the following organizations:

Cooperative Extension Service
College of Agriculture
University of Illinois
Illinois Natural History Survey
Illinois Department of Agriculture
Illinois Agricultural Aviation Association
Illinois Fertilizer and Chemical Association

The **planning committee** for the Illinois Agricultural Pesticides Conference '88 consisted of the following people:

Kevin Steffey and **Don Kuhlman**
Extension Entomology, University of Illinois and Illinois Natural History Survey
Loren Bode
Agricultural Engineering, University of Illinois
Tom Melton and **Barry Jacobsen**
Extension Plant Pathology, University of Illinois
Ellery Knake
Extension Weed Science, University of Illinois
Tom Walker
Illinois Department of Agriculture
Steve Benoit
Illinois Agricultural Aviation Association
Lloyd Burling, Darrell Deverman, and **Rich Fulscher**
Illinois Fertilizer and Chemical Association

PROGRAM

TUESDAY, JANUARY 5, 1988

ILLINOIS AGRICULTURAL AVIATION ASSOCIATION

Room 261, Illini Union
9:00 a.m. to 12:00 m.

NEW DEVELOPMENTS FROM INDUSTRY

Illini Rooms A and B, Illini Union

Rex Liebl Presiding

1:00 p.m.	Welcome, *K. Steffey*
1:10	Industry Session Overview, *R. Liebl*
1:15	The Sulfonylurea Herbicides, *E. Beyer*
1:45	The Imidazolinone Herbicides, *D. Shaner*
2:15	BASF, *B. Freed*
2:25	Chevron, *A. Fulford*
2:35	CIBA-Geigy, *D. Taylor*
2:45	American Cyanamid, *B. Gentsch*
2:55	Dow, *R. Dorich*
3:05	Break

Karl Kinney Presiding

3:25 p.m. DuPont, *R. McKelvey*

3:35 Elanco, *R. Schultz*

3:45 FMC, *R. Ehn*

3:55 American Hoechst, *W. Bertges*

4:05 ICI Americas, *R. Wolfe*

4:15 Mobay, *R. Myers*

4:25 Monsanto, *D. Schroeder*

4:35 PPG, *R. Cole*

4:45 Rhone-Poulenc, *W. Striegel*

4:55 Sandoz Crop Protection, *G. Hoffman*

5:05 Uniroyal, *E. Foland*

5:15 Adjourn to the **Mixer**

MIXER

Illini Room C, Illini Union
5:15 p.m. to 7:00 p.m.

This mixer is sponsored by the Illinois Fertilizer and Chemical Association and is intended for you to meet the speakers, sponsors, and committee members in an informal atmosphere. If you have any questions for the speakers who made presentations or if you just want to visit with friends, please stop by.

GENERAL SESSION

WEDNESDAY, JANUARY 6, 1988

Illini Rooms A, B, and C

8:00 a.m. Announcements, *K. Steffey*

HERBICIDE PERSISTENCE AND CROP TOLERANCE

Kevin Steffey Presiding

8:05 a.m. Herbicide Persistence—Where and Why, *R. Liebl*

8:20 Crop Tolerance and Carryover Concerns with Scepter, Pursuit, Command, and Chlorimuron: Results of Field Studies in Northern and Central Illinois, *B. Curran*

8:35 Crop Tolerance and Carryover Concerns with Scepter, Pursuit, Command, and Chlorimuron: Results of Field Studies in Southern Illinois, *R. Krausz*

8:50 Assessing Herbicide Residue in Soil, Water, and Plants, *D. Pike*

9:05 Genetic Differences in Herbicide Tolerance, *L. Paul*

CELEBRATING THE 40TH YEAR

9:20 a.m. A 40-Year Perspective of the "Spray School," *H. Petty*

9:35 The Future of the Illinois Agricultural Pesticides Conference, *K. Steffey*

9:40 A Dedication to "The Patriarchs," *K. Steffey*

9:45 Break

KEYNOTE SESSION: PESTICIDES, GROUNDWATER, AND ENVIRONMENTAL ISSUES

Don Kuhlman Presiding

10:00 a.m. EPA's Strategy for Agrichemicals in Groundwater
Dr. Susan Wayland, Deputy Director, Office of Pesticide Programs, U.S. EPA

10:30 Pesticide Monitoring of Community Water Wells in Illinois
Robert Clarke, Manager, Groundwater Section, Division of Public Water Supplies, Illinois EPA

10:50 Pesticides, Groundwater, and Risk Assessment
Dennis McKenna, Illinois State Geological Survey

11:10 Agrichemicals in Groundwater: University of Illinois Research Initiatives
Dr. Tom Bicki, Department of Agronomy, University of Illinois

11:30 The Illinois Environmental Council: Why, What, and Who?
Gerald Paulson, Executive Director, McHenry County Defenders

11:45 Questions and Answers

12:00 m. Lunch

RESEARCH REPORTS AND UPDATES

Pete Petty Presiding

1:00 p.m. Effect of Lorsban on Plant Growth, Stalk Rot, and Yield of Corn Hybrids, *W. Pedersen*

1:15 How Complex Should an Economic Threshold Be? *B. Ruesink*

1:40 Maximizing Herbicide Performance While Minimizing Costs, *F. Baldwin*

2:00 Designing Herbicide Combinations, *M. McGlamery*

2:15 1988 Distribution of the Soybean Cyst Nematode in Illinois: Results of an Aerial Survey, *T. Melton*

2:25 Herbicides As Potential Hatching Factors for the Soybean Cyst Nematode, *G. Noel*

2:37 Insecticide Resistance: Current Status and Future Challenges, *R. Weinzierl*

3:02 Break

Steve Benoit Presiding

3:15 p.m. Pesticide Regulation: A Step Toward the Future, *T. Walker*

3:30 Corn Rootworm Control: Do Root Ratings Tell the Whole Story? *K. Steffey*

3:45 DIMBOA in Corn: A Preformed Chemical Defense Mechanism to Lesion Nematodes, *L. Vaillancourt*

4:00 Weed Control for Conservation Tillage Systems, *L. Wax*

4:15 Incorporation Techniques for Reduced Tillage Systems, *S. Pearson*

4:30 Sudden Death Syndrome of Soybean: Current Research and Directions, *W. Kirby*

4:40 Will My Computer Tell Me What To Do for Weed Control? *F. Baldwin*

4:55 Some Highlights of Weed Science Research in 1987, *E. Knake*

5:10 Adjourn

Pesticide Applicator Training for Field Crop and Demonstration and Research Pest Control Categories

7:30 p.m. WEDNESDAY EVENING
Room 314, Illini Union

Concurrent training sessions for the field crop and research and demonstration pest control categories will be offered. Comprehensive training will include safe handling of pesticides, pesticide poisoning, pest identification, calibration, and laws and regulations.

A person desiring to become certified as an applicator must first take and pass the General Standards examination before taking any of the applicator category examinations. However, there will be no training for the General Standards examination. Manuals and handout material will be available.

THURSDAY, JANUARY 7, 1988

Darrell Deverman Presiding

8:15 a.m. The Biology of Perennial Weeds, *M. Horak*

8:30 Clopyralid and Fluroxypyr for Control of Hemp Dogbane and Common Milkweed, *M. Orfanedes*

8:45 Bugs, Corn, and Set-Aside Acres, *D. Kuhlman*

9:00 Opportunities for Herbicides with Set-Aside, *E. Knake*

9:15 Illinois Animal Poison Information Center: Domestic Animals and Agricultural Pesticides, *V. Beasley*

9:35 New Developments Regarding Extended Diapause in Northern Corn Rootworms: Research and Survey Results, *E. Levine*

9:55 Can We Control Pesticide Runoff? *A. Felsot*

10:10 Break

Don Meyer Presiding

10:25 a.m. Bean Leaf Beetle Feeding on Pods: Effects on Soybean Yield and Seed Quality, *M. Kogan*

10:40 Herbicide-Rhizoctonia Interactions on Soybean Seedling Development, *W. Kirby*

10:50 Overview of Weed Control for Soybeans, *G. Kapusta*

11:05 Insects in Stored Grain: Illinois Survey Findings and Management Recommendations, *R. Weinzierl*

11:20 Effects of Low Rates of Fungicides on Storage Molds of Corn, *D. White*

11:40 Adjuvants for Postemergence Herbicides: Fundamentals, *F. Koppatschek*

11:55 Adjuvants for Postemergence Herbicides: Field Results, *R. Fielding*

12:10 Herbicides on the Horizon, *M. McGlamery*

12:25 Adjourn

Pesticide Applicator Examinations

1:15 to 4:30 p.m. THURSDAY AFTERNOON
Room 314, Illini Union

Written examinations for all commercial pesticide applicator pest control categories will be offered. General Standards examinations will also be available. A person may take as many examinations as he or she can complete during the allotted time. A passing score of 70 percent is required on both the General Standards and category examinations in order to become a certified applicator.

PROGRAM PARTICIPANTS

Ford Baldwin, Extension Weed Scientist, Section Leader—Pest Management, University of Arkansas, Little Rock, AR

Val Beasley, Assistant Professor of Veterinary Toxicology and Associate Director of the Illinois Animal Poison Information Center, University of Illinois, Urbana, IL

Steve Benoit, President, Illinois Agricultural Aviation Association, Benoit Aerial Spraying, Inc., Bourbonnais, IL

William Bertges, Field Technical Group Manager, Northern Region, Hoechst- Roussel Agri-Vet Co., Burnsville, MN

Elmo Beyer, Director, Discovery Research, E.I. DuPont de Nemours & Co., Wilmington, DE

Tom Bicki, Assistant Professor of Agronomy, Department of Agronomy, University of Illinois, Urbana, IL

Robert Clarke, Manager, Groundwater Section, Division of Public Water Supplies, Illinois Environmental Protection Agency, Springfield, IL

Rick Cole, Biochemical Field Research and Development Representative, PPG Industries, Inc., Champaign, IL

Bill Curran, Assistant Agronomist in Integrated Pest Management, Weed Science, Department of Agronomy, University of Illinois, Urbana, IL

Darrell Deverman, President, Atlanta Agricultural Center, Inc., Atlanta, IL, and Member, Board of Directors, Illinois Fertilizer and Chemical Association

Rod Dorich, Technical Service and Development, Industrial Herbicides, Agricultural Products Department, Dow Chemical Co., Indianapolis, IN

Robert Ehn, Technical Service Manager, Midwest Region, Agricultural Chemical Group, FMC Corp., Omaha, NE

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Brian Freed, Market Development Technical Representative, Agricultural Chemicals Group, BASF Corp., Dawson, IL

Arthur Fulford, Field Technical Specialist, Chevron Chemical Co., Memphis, TN

Bryan Gentsch, Technical Service Representative, American Cyanamid Co., Crystal Lake, IL

George Hoffman, Product Development Field Representative, Sandoz Crop Protection, Urbana, IL

Michael Horak, Graduate Research Assistant, Weed Science, Department of Agronomy, University of Illinois, Urbana, IL

George Kapusta, Professor of Plant and Soil Science, Weed Science, Southern Illinois University, Carbondale, IL

Karl Kinney, Assistant Research Biologist, Section of Economic Entomology, Illinois Natural History Survey, Champaign, IL

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Ellery Knake, Professor of Weed Science, Department of Agronomy, University of Illinois, Urbana, IL

Marcos Kogan, Professional Scientist, Section of Economic Entomology, Illinois Natural History Survey, and Professor of Agricultural Entomology, University of Illinois, Champaign, IL

Fritz Koppatschek, Graduate Research Assistant, Weed Science, Department of Agronomy, University of Illinois, Urbana, IL

Ron Krausz, Crops Testing Technician, Belleville Research Center, Southern Illinois University, Belleville, IL

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Rex Liebl, Assistant Professor of Weed Science, Department of Agronomy, University of Illinois, Urbana, IL

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Don Meyer, Extension Adviser—Agriculture, McLean County, Cooperative Extension Service, University of Illinois, Bloomington, IL

Randy Myers, Senior Field Development Representative, Agricultural Chemicals Division, Mobay Corp., Urbana, IL

Gregory Noel, Associate Professor of Plant Pathology, Department of Plant Pathology, University of Illinois, Urbana, IL

Mike Orfanedes, Graduate Research Assistant, Weed Science, Department of Agronomy, University of Illinois, Urbana, IL

Lyle Paul, Associate Agronomist and Superintendent, Northern Illinois Agronomy Research Center, University of Illinois, DeKalb, IL

Gerald Paulson, Executive Director, McHenry County Defenders, Woodstock, IL, and Past President, Illinois Environmental Council Board of Directors

Steve Pearson, Extension Assistant in Agricultural Engineering, Department of Agricultural Engineering, University of Illinois, Urbana, IL

Wayne Pedersen, Associate Professor of Plant Pathology, Department of Plant Pathology, University of Illinois, Urbana, IL

H.B. "Pete" Petty, Professor Emeritus of Agricultural Entomology, University of Illinois and Illinois Natural History Survey, Champaign, IL

David Pike, Agronomist, Weed Science, Department of Agronomy, University of Illinois, Urbana, IL

William Ruesink, Head, Section of Economic Entomology, Illinois Natural History Survey, and Head, Office of Agricultural Entomology, University of Illinois, Champaign, IL

Dan Schroeder, Product Development Associate, Monsanto Co., Decatur, IL

Rod Schultz, Plant Science Representative, East Region, Plant Science Field Research, Elanco Products Co., Eli Lilly and Co., Mansfield, IL

Dale Shaner, Associate Research Fellow, American Cyanamid Co., Agricultural Research Division, Princeton, NJ

Kevin Steffey, Associate Professor of Agricultural Entomology, Office of Agricultural Entomology, University of Illinois and Illinois Natural History Survey, Champaign, IL

William Striegel, Field Development Representative, Rhone-Poulenc Ag Co., Morton, IL

T. Don Taylor, Senior Scientist, Field Research, CIBA-Geigy Corp., Research Station, Dewey, IL

Lisa Vaillancourt, Graduate Research Assistant, Department of Plant Pathology, Urbana, IL

Tom Walker, Administrative Assistant, Bureau of Plant and Apiary Protection, Illinois Department of Agriculture, Springfield, IL

Loyd Wax, Agronomist, USDA, and Professor of Weed Science, Department of Agronomy, University of Illinois, Urbana, IL

Susan Wayland, Deputy Director, Office of Pesticide Programs, United States Environmental Protection Agency, Washington, D.C.

Rick Weinzierl, Assistant Professor of Agricultural Entomology, Office of Agricultural Entomology, University of Illinois and Illinois Natural History Survey, Champaign, IL

Don White, Associate Professor of Plant Pathology, Department of Plant Pathology, University of Illinois, Urbana, IL

Ron Wolfe, Market Development Representative, ICI Americas, Inc., Monticello, IL

Pesticide Training and Certification Clinics--1988

Pesticide Training and Certification Clinics will be offered throughout the state with some notable program changes. Most of the category clinics will be two days long instead of one day long as offered previously. These new clinics will include information on the new Endangered Species Act presented by personnel from the U.S. Environmental Protection Agency and Illinois Environmental Protection Agency. Information will also be presented on the Groundwater Pesticide Contamination Problem. Included in the presentations on insects, weeds, and diseases will be additional updated information to help keep you on the "cutting edge" of new developments in these fields.

Training

Registration will begin at 7:30 a.m. with training beginning at 8:00 a.m. A registration fee, payable at the door, will be charged at each clinic. Two-day clinics will be charged a single registration fee, whether or not both days are attended. No advance registration is required, except as noted on February 3, March 8, 9, 15, 16, 29, and April 14. On those dates, preregistered individuals may be given seating priority for training and testing.

Commercial applicator category training clinics will be given for field crops, seed treatment, ornamental, turf, and right-of-way.

Testing

Testing will begin at 1:00 p.m. (2:00 p.m. at many General Standards Clinics) and should be completed by 4:00 p.m. Two-day category clinics (Field Crops, Urban Clinics) will have testing in the afternoon of the second day only. Tests will be graded and results made available immediately after testing.

Those attending a clinic only to take examinations will be charged a registration fee to help cover the cost of facilities.

You must pass the General Standards Certification examination before you will be allowed to take a category examination. **Category tests will not be available at General Standards Clinics.** All tests will be available at category clinics. For testing sessions, please bring your most current license or all past test results.

The State of Illinois Department of Agriculture administers both the general standards and category examinations. Illinois law requires a person who applies a pesticide for hire outside of a structure to be licensed by the Illinois Department of Agriculture. Testing, certification, and licensing questions should be sent to Bill Anderson, Illinois Department of Agriculture, State Fairgrounds, P.O. Box 19281, Springfield, Illinois 62794-19281, or call

(217)785-2427. In northeastern Illinois, Stan Smith can be contacted at (312)990-8256.

The Cooperative Extension Service of the University of Illinois writes the study guides and teaches the training sessions. Pesticide training clinic questions should be sent to Phil Nixon, University of Illinois, 172 Natural Resources Bldg., 607 E. Peabody Drive, Champaign, IL 61820, or call (217)333-6650. In northeastern Illinois, contact Fred Miller at (312)990-0760.

Study guides can be purchased from county Cooperative Extension Service Offices and from the University of Illinois office listed above. They will also be available at each clinic. Illinois Pesticide Applicator Study Guides are available for General Standards and category manuals are available for Turfgrass, Ornamental, Field Crops, Seed Treatment, and Right-of-Way. Study packets for other categories are also available, but only from the University of Illinois campus address listed above.

1987 - 1988 PESTICIDE TRAINING AND CERTIFICATION CLINICS

GENERAL STANDARDS CLINICS

Date	City	Location, Time, Fees
Dec. 2	Teutopolis	Knights of Columbus Hall, S. of Rt. 40 on Vine St. 8:00 a.m., $10.00 Registration
Dec. 3	Peoria	Holiday Inn - Brandywine, I-74 & Exit 89 on Rt. 150. 8:00 a.m., $10.00 Registration
Jan. 19	Mt. Vernon	Community Center, City Park, 27th & Logan. 8:00 a.m., $10.00 Registration
Jan. 20	Ottawa	Pitstick Pavilion, 4 mi. N of I-80 on Rt. 23. 8:00 a.m., $10.00 Registration
Jan. 21	Champaign	Round Barn, 1 Blk. W of Mattis Ave. on Springfield Ave. 8:00 a.m., $10.00 Regis.
Feb. 3	Waukegan	Lakehurst Mall, Junc. Ill. 43 & 120. 8:00 a.m., $5.00 Registration. Pre-registration required, call (312) 223-8627
Feb. 18	Alsip	Holiday Inn, Junc. 127th St. & I-294. 8:00 a.m., $5.00 Registration. Pre-registration required, call (312) 532-4369
Mar. 8	Glencoe	Chicago Botanic Garden, Lake-Cook Rd. east of I-94. 8:00 a.m., $5.00 Registration. Pre-registration required, call (312) 991-1160
Mar. 15	Joliet	Holiday Inn, Larkin Ave. & I-80. 8:00 a.m., $5.00 Registration. Pre-registration required, call (815) 727-9296
Mar. 22	Fairview Hts.	Ramada Inn, I-64 & Rt. 59. 8:00 a.m., $10.00 Registration
Mar. 23	Bloomington	Ramada Inn, I-55 & 74 at Rt. 9. 8:00 a.m., $10.00 Registration
Mar. 29	Crystal Lake	Hob Nob II Restaurant, Junc. Rt. 14 &31. 8:00 a.m., $5.00 Registration. Pre-registration required, call (815) 338-3737
Apr. 12	Springfield	Regional Extension Office, State Fairgrounds. 8:00 a.m., $10.00 Registration
Apr. 13	Rockford	Clock Tower Hotel, I-90 & Bus. 20. 8:00 a.m., $10.00 Registration
Apr. 13	Wheaton	DuPage Co. Fairgrounds, Manchester Rd. 8:00 a.m., $5.00 Registration
Apr. 19	Glencoe	Chicago Botanic Garden, Lake-Cook Rd. east of I-94. 8:00 a.m., $5.00 Regis.

TESTING ONLY
No Training Will Be Given

Date	City	Location, Time, Fees
Mar. 30	Duquoin	Duquoin State Fairgrounds, On Rt. 51. 8:00 a.m. - noon. All Tests Available.
Jun. 2	Wheaton	Dupage Co. Fairgrounds, Manchester Rd. 8:00 a.m. - noon. All Tests Available.

1987 - 1988 PESTICIDE TRAINING AND CERTIFICATION CLINICS

FIELD CROPS CLINICS

Date	City	Location, Time, Fees
Feb. 16-17	Rock Falls	Ramada Inn, Junc. Ill. 5 & Rt. 88. 8:00 a.m., $10.00 Registration
Feb. 18-19	Springfield	Holiday Inn-East, I-55 & Stevenson Dr. 8:00 a.m., $10.00 Registration
Feb. 23-24	Mt. Vernon	Ramada Inn, I-57 & I-64. 8:00 a.m., $10.00 Registration
Feb. 25-26	Kankakee	Holiday Inn-Bradley, I-57 & Rt. 50. 8:00 a.m., $10.00 Registration

TURF AND ORNAMENTALS - URBAN CLINICS

Date	City	Location, Time, Fees
Feb. 18-19	Springfield	Holiday Inn-East, I-55 & Stevenson Dr. 8:00 a.m., $10.00 Registration
Feb. 23-24	Mt. Vernon	Ramada Inn, I-57 & I-64. 8:00 a.m., $10.00 Registration
Mar. 1-2	Galesburg	Holiday Inn, 2 mi. W of I-74 on U.S. 34. 8:30 a.m., $10.00 Registration
Mar. 9	Glencoe	Chicago Botanic Garden, Lake-Cook Rd. East of I-94. 8:00 a.m., $5.00 Registration. Pre-registration required, call (312) 991-1160
Mar. 16	Joliet	Holiday Inn, Larkin Ave. & I-80. 8:00 a.m., $5.00 Registration. Pre-registration required, call (815) 727-9296
Apr. 14	St. Charles	Kane Co. Extension Office, N. of Rt. 38 on Randall Rd. 8:00 a.m., $5.00 Registration. Pre-registration required, call (312) 584-6166
Apr. 20	Glencoe	Chicago Botanic Garden, Lake-Cook Rd. East of I-94. 8:00 a.m., $5.00 Registration

One-day Urban Clinics in northeastern Illinois (Glencoe, Joliet, St. Charles) are preceeded, on the day before, by a General Standards Clinic listed on the opposite page.

RIGHT-OF-WAY CLINICS

Date	City	Location, Time, Fees
Feb. 19	Springfield	Holiday Inn East, I-55 & Stevenson Dr. 8:45 a.m., $10.00 Registration
Feb. 24	Mt. Vernon	Ramada Inn, I-57 & I-64. 8:45 a.m., $10.00 Registration
Mar. 2	Galesburg	Holiday Inn, 2 mi. W of I-74 on U.S. 34. 8:45 a.m., 10.00 Registration

Workshops Offered in 1988

FOURTEENTH ANNUAL ILLINOIS CROP PROTECTION WORKSHOP

Extension specialists and research personnel with the University of Illinois, College of Agriculture, and the Illinois Natural History Survey are offering a Crop Protection Workshop from March 9 to 11, 1988, at the University of Illinois Illini Union, Urbana. Advance registration will be required.

The objectives of the workshop are to give in-depth training in diagnosing pest problems, troubleshooting in the field, and identifying insect, weed, and disease pests, as well as life cycles, thresholds, plant nutrient deficiencies, and other factors that affect crop production decisions.

Specialists in entomology, weed science, agronomy, plant pathology, and agricultural engineering from the University of Illinois and the Illinois Natural History Survey will conduct training sessions on the above topics. Out-of-state speakers will also give presentations on subjects of particular interest. About eighteen hours will be spent in group sessions.

The registration fee for the workshop is $40 and will include the cost of the workshop but will not cover meals or lodging. Further information about the workshop can be obtained at the registration desk at the Illinois Agricultural Pesticides Conference or from Donald E. Kuhlman, 172 Natural Resources Building, 607 East Peabody Drive, Champaign, Illinois 61820 (Phone: (217)333-6653).

FIELD CROP PEST MANAGEMENT SCOUT TRAINING SCHOOLS

Two sessions of a pest management scout training short course will be offered in 1988. These short courses are being offered at two separate times to accommodate those persons who will monitor field crops for pest problems. The courses will be taught by Extension specialists in weed science, agronomy, entomology, and plant pathology from the University of Illinois and the Illinois Natural History Survey. The dates of the short courses are:

Scout School I--March 28-29, 1988
Scout School II--March 30-31, 1988

The material presented will be identical for both sessions. Further information about the workshop can be obtained at the registration desk at the Illinois Agricultural Pesticides Conference or from Tom Melton, S-522 Turner Hall, 1102 S. Goodwin Avenue, Urbana, Illinois 61801 (Phone: (217)333-7515).

WHICH WORKSHOP IS FOR YOU?

Each year a number of people inquire about the difference between the crop protection workshop and the pest management scout training short course.

The Crop Protection Workshop is intended for those individuals who are concerned with the research that goes into pest management. Topics presented represent the current research and ideas that will provide the basis for future pest management decisions. Farmers, agribusiness people, and Extension advisers represent the largest portion of the 300 people in attendance.

The Field Crop Pest Management Scout Training schools are intended for those who wish to learn the what, how, where, and when of field crop scouting. The lab sessions are approximately four hours each and cover the identification of weeds, insects, and plant diseases and the procedures needed to accurately scout and report the findings. Farmers and field scouts employed by private consultants comprise the largest segment of the audience.

If you are still unsure about which workshop to attend, contact Donald E. Kuhlman, Illinois Natural History Survey, 172 Natural Resources Building, 607 East Peabody Drive, Champaign, Illinois 61820 (Phone: (217)333-6653).

Newsletters from the University of Illinois College of Agriculture

FARM ECONOMICS FACTS AND OPINIONS--Economic principles applied to farm problems such as marketing strategies, crop and livestock production decisions, government and institutional policies. Eighteen issues per year.

WEEKLY OUTLOOK--Anticipates reports and interprets current market information--supply, demand, and price outlook--for agricultural products. Issued weekly except for last two weeks of December.

LIVESTOCK PRICES AND MARKETS--Forecasts of prices and production for hogs (four issues) and cattle (two issues) following inventory reports. Includes inventory data, forecasting methods, and discussions of pricing strategies. In addition, two issues on developments in livestock markets and marketing methods. Eight issues per year.

GRAIN PRICE OUTLOOK---Four issues each on corn and soybeans. An in-depth analysis of supply, demand, and price outlook for corn and soybeans. Also includes a discussion of storage and pricing strategies for producers. Eight issues per year.

ILLINOIS IRRIGATION NEWSLETTER--Presents information on new irrigation techniques and equipment; some in-depth treatment of specific topics of interest to irrigators. Ten issues per year.

SWINE REPORT--Current information on swine feeding, breeding, management, and engineering. Issued quarterly.

COW-CALF REPORT--Current information on cow-calf management, feeding, breeding and marketing. Provides the latest research findings and timely management tips for commercial and purebred producers. Issued quarterly.

FEEDLOT REPORT--Current research findings and timely information on feedlot nutrition and management. Issued quarterly.

ILLINOIS DAIRY DIGEST--Provides the latest dairy research information available from the U of I and other sources; practical, timely tips to help producers make management decisions; announcements of educational events. Four issues per year.

SHEEP REPORT--Current information on breeding, feeding, management, and health. Research updates and current information on educational activities. Six issues per year.

ILLINOIS POULTRY SUGGESTIONS--Latest information on management, marketing, business and regulatory developments in the poultry industry. For hatchery operators, commercial poultry producers, small flock owners and poultry service personnel. Six issues per year.

BEES AND HONEY--Presents basic beekeeping information including research, statistics, diseases and pests, as well as timely tips. Issued quarterly.

ILLINOIS FOREST MANAGEMENT NEWSLETTER--Features helpful management information and timely tips for woodland owners on silviculture, tree planting, wildlife management, forest investments and taxes, marketing, harvesting and utilization, forest insect and disease problems, residential tree care and the care of wood products around the home. Two issues per year.

ILLINOIS VEGETABLE FARMER'S NEWSLETTER--Provides production, harvest and handling, and marketing advice for commercial producers in the Midwest. News and updates from university and Extension staff are highlighted. Four issues per year.

INSECT, WEED AND PLANT DISEASE SURVEY BULLETIN--Weekly reports on the current agricultural insect, weed, and plant disease situation with advice on control methods. Also covers new developments in pesticide application techniques. Issued weekly April-August.

HOME, YARD, AND GARDEN PEST NEWSLETTER--Insect, weed, and plant disease pests of the home and garden. Current controls, application equipment and methods, storage and disposal of pesticides, plus other topics. Issued weekly April-July; biweekly in August.

SPRAY SERVICE REPORT--Provides information on commercial fruit culture, insect and disease problems,and recommended control measures. Seventeen issues per year concentrated during the growing season. Issued weekly April-May; bi-weekly March and June; three-week intervals July-August; plus special issues October-March.

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The Sulfonylurea Herbicides

E. Beyer

INTRODUCTION

The sulfonylurea herbicides, discovered in 1975 by Dr. George Levitt of DuPont, have emerged as a major new class of herbicides and a significant advance in chemical weed control technology. With their unprecedented herbicidal activity, use rates have plummeted resulting in application rates of grams rather than kilograms per hectare. The need for such low-dosage compounds with greater selectivity and safety to man and the environment are important factors contributing to the rapid success of these new materials. This highly versatile chemistry has the potential for solving many of the existing weed control problems in agriculture.

CHEMISTRY

The sulfonylurea herbicides are represented by the general structure shown in Figure 1.

The molecule is composed of an aryl group, the sulfonylurea bridge (from which they get their name), and a nitrogen-containing heterocycle. When the aryl portion is a phenyl group, the highest herbicidal activity occurs when this group contains a substitutent *adjacent* to the bridge. Sulfonylureas containing aryl groups other than a phenyl are also biologically active (for example, thiophene, furan, pyridine). The greatest activity generally occurs when the heterocyclic portion is a symmetrical-pyrimidine or triazine containing lower alkyl or alkoxy substituents at X and Y. Other active heterocycles include triazoles, asymmetrical-triazines, fused-ring pyrimidines, and pyridines. Sulfonylureas with an unmodified bridge are usually the most active, but $-SO_2HNC(S)NH-$, $-OSO_2NHCONH-$, $-SO_2NHCON(CH_3)-$, and $-CH_2SO_2NHCONH-$ are also active.

Selective Sulfonylurea Herbicides

The structure, common name, trade name, use, and application rate of several selective sulfonylureas commercialized by DuPont since 1982 are shown in Figure 2.

Synthesis

The preferred route for commercial manufacture of sulfonylureas is the coupling of any aryl sulfonylisocyanate with a heterocyclic amine.

$$ArSO_2NCO + H_2NHet \dashrightarrow ArSO_2NHCONHHet$$

By combining a solution of the aryl sulfonylisocyanate with a suspension of the heterocyclic amine in an inert organic solvent such as xylene, the sulfonylurea precipitates as a fine crystalline solid. The sulfonylisocyanates are easily prepared by the reaction of phosgene with a sulfonamide, in the presence of an alkyl isocyanate, in an inert organic solvent at 120° to 140°C.

Physical and Chemical Properties

The sulfonylureas generally exhibit moderate melting points, low octanol/water partition coefficients at neutral pH, low vapor pressures, and low to moderate water solubilities at neutral pH. They are weak acids with dissociation constants (pK_a's) ranging from 3.3 to 5.2; thus, they are about as acidic as acetic acid ($pK_a = 4.75$). Accordingly, pH greatly affects their water solubility (for example, water solubility of chlorsulfuron is 60 ppm at pH 5, while at pH 7 it is 7000 pm).

TOXICOLOGY

Sulfonylurea herbicides have low acute oral, dermal, and inhalation toxicities. The acute oral LD_{50} value of these compounds is greater than 4100 mg/kg. They are not mutagenic or teratogenic and they exhibit low toxicity to fish, wildlife, and honeybees. Subchronic feeding and reproduction studies, as well as chronic feeding studies in rats, mice, and dogs, have produced favorable results.

BIOLOGY

Sulfonylureas are potent inhibitors of plant growth. While seed germination is not usually affected, subsequent root and shoot growth are severely inhibited in sensitive seedlings. Growth inhibition is very rapid and, depending on the plant species, dose, and environmental conditions, a variety of secondary plant symptoms often develop such as anthocyanin formation, abscission, vein discoloration, terminal bud death, chlorosis, or necrosis. Secondary effects are often slow to develop with plant death sometimes not occurring until a week or more following treatment. Sulfonylureas are taken up readily by both roots and foliage; once inside the plant they are translocated via the xylem and phloem.

MODE OF ACTION

Initial studies at DuPont by Dr. Tom Ray established that the sulfonylurea herbicides are rapid and potent inhibitors of cell division and growth. For example, the threshold concentration of chlorsulfuron inhibition of cell division in corn, pea, and Jerusalem artichoke tissues ranges from 2.8 to 28 ηM (1 to 10 ppb) and is apparent after 2 to 4 hours of treatment. Biochemical and physiological studies have demonstrated that under conditions where cell division is reduced 80 to 90 percent there is no direct effect on respiration, photosynthesis, or synthesis of RNA, DNA, proteins, or lipids. Moreover, current evidence indicates the sulfonylurea herbicides do not directly block the growth-promoting action of the plant hormones (for example, auxins, gibberellins, and cytokinins) nor do they exert their primary effect through an effect on ethylene.

The discovery of the target site of action of the sulfonylurea herbicides was made by Drs. Bob LaRossa and John Schloss of DuPont using bacteria. They identified several bacterial species (*Salmonella typhimurium*) where growth could be inhibited by the sulfonylurea herbicides, albeit at relatively high concentrations compared to those required to inhibit plant growth (μM for bacterial vs. ηM concentrations for plants). Furthermore, they observed that certain branched-chain amino acids, such as isoleucine could reverse this growth inhibition in bacteria. These and other experiments suggest that the sulfonylureas inhibit some step in the branched-chain amino acid biosynthetic pathway. Subsequent work by these investigators identified the target site as the enzyme, acetolactate synthase. This enzyme is also known as acetohydroxyacid synthase (AHAS). It is a key enzyme in the branched-chain amino acid biosynthetic pathway of bacteria, fungi, and higher plants. The enzyme requires thiamine pyrophosphate and Mg^{++}, as well as flavin adenine dinucleotide (FAD). As shown in Figure 3, the acetolactate synthase (ALS) enzyme catalyzes: a) the condensation of two molecules of pyruvate to form CO_2 and α-acetolactate, which leads to valine synthesis; and, (b) the condensation of one molecule of pyruvate with α-ketobutyrate (oxobutyrate) to form CO_2 and α-aceto-α-hydroxybutyrate, which leads to isoleucine formation. Dr. Tom Ray of DuPont has extended these studies to higher plants, and together with Dr. Roy Chaleff and Jeff Mauvais, these investigators have provided unequivocal biochemical and genetic evidence that ALS is the primary target site of action of the sulfonylurea herbicides.

The I_{50} value, or the concentration of sulfonylurea herbicide required to inhibit the ALS enzyme by 50 percent *in vitro* in a 30-minute assay, generally ranges from 1 to 100 ηM with most of the highly active sulfonylurea herbicides having I_{50}'s of around 10 ηM.

BASIS OF CROP SELECTIVITY

Enormous differences exist in the sensitivity of plants to specific sulfonylurea herbicides. For example, differences in sensitivity to chlorsulfuron of up to 4000-fold are observed between highly tolerant plants such as wheat, barley, and wild oats and highly sensitive plants such as mustard, sugar beets, soybeans, and cotton. It has been demonstrated that such large differences are not caused by differences in sensitivities of the ALS enzymes from these plants or by differences in uptake or translocation.

The underlying basis of these large differences was first uncovered by Dr. Phil Sweetser of DuPont. He demonstrated that tolerant plants, but not sensitive ones, could rapidly metabolize the sulfonylurea herbicides to inactive products. The site of attack by various crops leading to sulfonylurea inactivation or detoxification is summarized in Figure 4.

Based on current evidence, the chemical and biological rules governing sulfonylurea tolerance include: (a) the presence of a metabolizable site in the molecule; (b) rapid metabolism with a half life of only a few hours; and, (c) the formation of products with greatly reduced herbicidal potency.

SAFENERS

A number of safeners (antidotes) have been found to extend or improve the selectivity of the sulfonylureas. For example, the well known safener, 1,8-naphthalic anhydride, applied as a seed treatment to corn at 0.5 percent (weight/weight) reduced injury caused by a 5 g/ha postemergence treatment of chlorsulfuron from 60 to 10 percent. To date, the only practical safening combination that has been developed is bensulfuron methyl with certain thiocarbamate rice herbicides. Fortunately, these compounds not only safen bensulfuron methyl on rice, but they also provide excellent barnyardgrass control, a weed not well controlled by bensulfuron methyl at low rates. The mechanism for this safening action is an enhancement or "turning-on" of the rate of sulfonylurea inactivation or detoxification in rice.

SOIL DISSIPATION AND MOVEMENT

Sulfonylureas degrade under field conditions at rates similar to, and often faster than, many conventional herbicides. The most important pathways of sulfonylurea degradation or dissipation in soil are chemical hydrolysis and microbial breakdown. Photolysis and volatilization are relatively minor processes. To assess the relative importance of the two major processes, degradation in sterilized (no microbial activity) and nonsterilized soil is compared. Because only chemical hydrolysis occurs in sterile soil, the difference in the rate of breakdown under sterile and nonsterile conditions can be used to estimate the relative contributions of chemical hydrolysis and microbial breakdown. Differences in the rate of breakdown of chlorsulfuron at 30°C under sterilized conditions, where chemical hydrolysis predominates, and under nonsterilized conditions, where microbial breakdown is also a factor, is illustrated for three soil types ranging in pH from 5.9 to 8.0 (Figure 5).

As can be seen in Figure 5, chemical hydrolysis is fastest in low pH soils and as the soil pH increases this mode of dissipation rapidly declines. Under alkaline soil conditions, where rates of chemical hydrolysis are much reduced, microbial breakdown is the predominant dissipation mechanism. The facts having the greatest influence on chemical hydrolysis and microbial breakdown include temperature, pH, moisture, and soil organic matter. Overall breakdown is generally the fastest in warm, moist, light-textured, low pH soils and slowest in cold, dry, heavy, high pH soils.

Mobility of a particular sulfonylurea herbicide generally increases with increasing soil pH and decreasing organic matter. As a class, the sulfonylureas are characterized as relatively mobile compounds. However, bensulfuron methyl binds more tightly to soil than do most sulfonylureas; thus, it is generally much less mobile.

As illustrated in Figure 6, the sometimes long residual activity for chlorsulfuron that has been observed by replanting highly sensitive crops into sulfonylurea-treated soil is caused primarily by the very high susceptibility of the rotational crop and not to an inherently slow rate of dissipation. Bensulfuron methyl, with its tighter soil binding characteristics, has relatively low soil residual activity compared to many other sulfonylureas.

BIOTECHNOLOGY

Traditionally, herbicide chemistry has been tailored to kill weeds without harming the crop. Today, another complementary method is available for achieving crop safety. Using the techniques embodied in biotechnology, Drs. Roy Chaleff and Tom Ray of DuPont have successfully obtained plants with greatly increased levels of resistance to the sulfonylurea herbicides. For example, using plant cell and tissue culture selection techniques, tobacco plants were obtained that exhibited more than 1000-times the resistance of normal cultivars. The reason for the increased level of resistance was found to be due to an altered, less sensitive form of the sulfonylurea target enzyme, acetolactate synthase (ALS). The resistant gene has been isolated and sequenced and genetic engineering research is underway to insert this gene into other crops.

Reference

E.M. Beyer, Jr., M.J. Duffy, J.V. Hay, and D.D. Schlueter. 1987. 'Sulfonylureas' Volume III. In: *Herbicides--Chemistry, Degradation and Mode of Action*, Editors: P.C. Kearney and D.D. Kaufman. Marcel Dekker, Inc., NY.

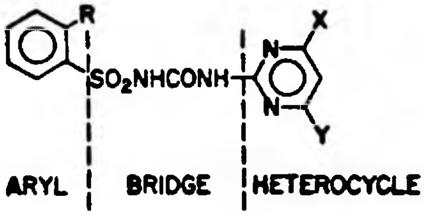


Figure 1 (LEFT). The general structure of sulfonylurea herbicides.

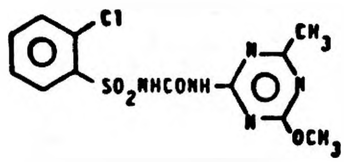
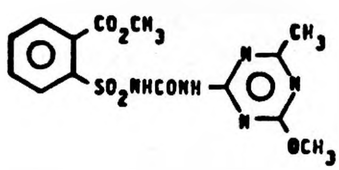
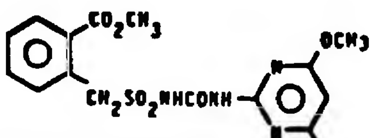
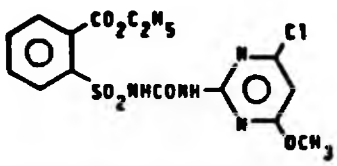
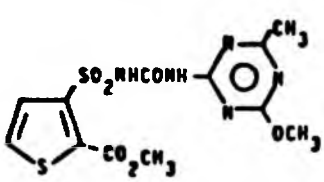
Structure/Common Name	Trade Name(s)	Use	Rate (g ai/ha)
 Chlorsulfuron	Glean®	Cereals	4-26
 Metsulfuron Methyl	Ally®/Allie®/ Gropper®	Cereals	2-8
 Bensulfuron Methyl	Londax®	Rice	20-75
 Chlorimuron Ethyl	Classic®	Soybeans	8-13
 DPX-M6316	Harmony®	Cereals	10-35

Figure 2. The structure, common name, trade name, use, and application rate of selective sulfonylureas commercialized by DuPont since 1982.

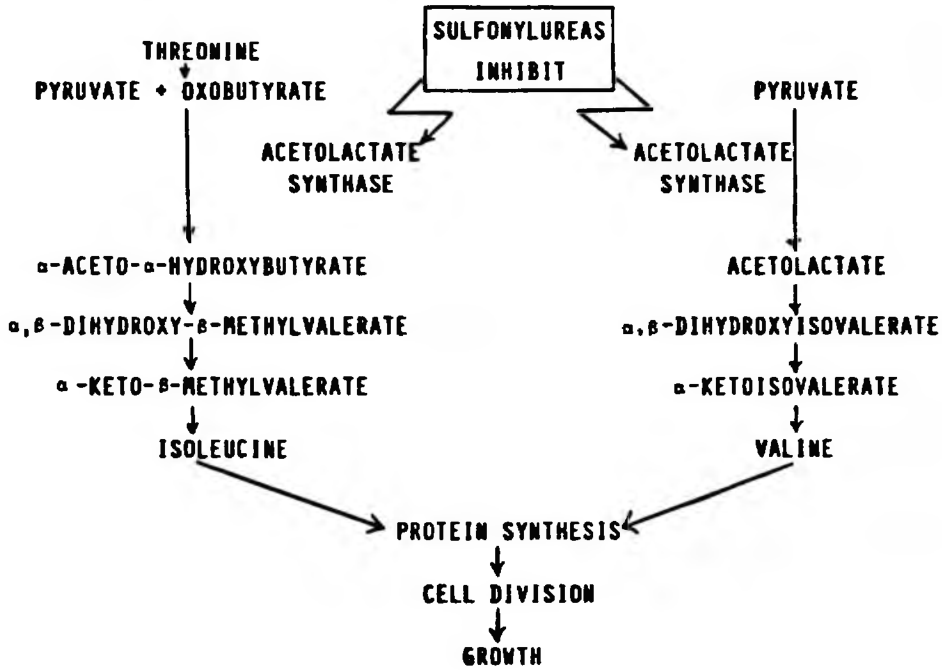


Figure 3. The biosynthetic pathway for valine and isoleucine.

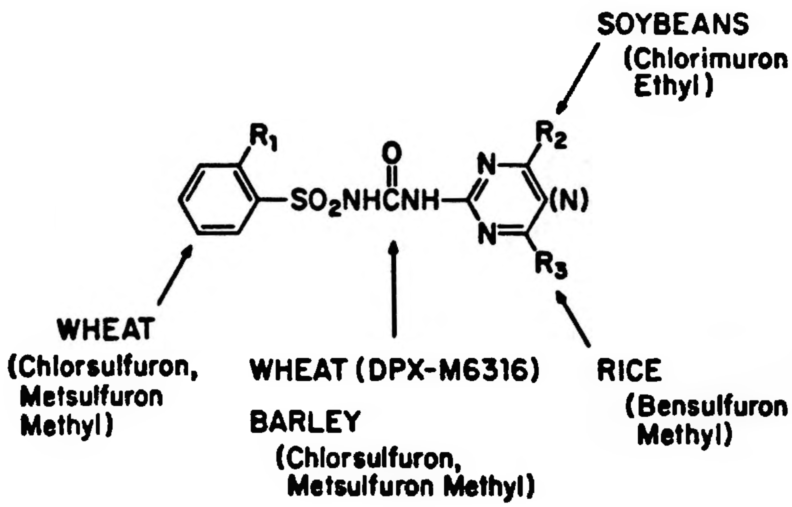


Figure 4. The site of attack by various crops leading to sulfonylurea inactivation or detoxification.

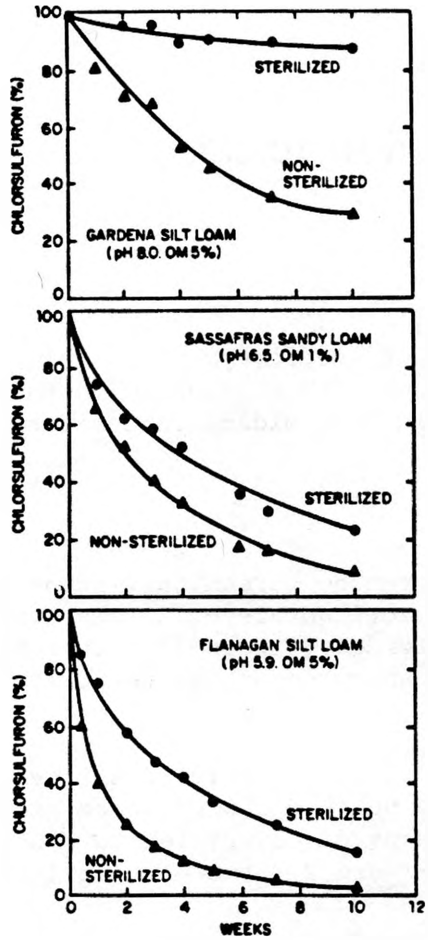


Figure 5. Differences in breakdown rate of chlorsulfuron for three soil types under sterilized conditions, where chemical hydrolysis predominates, and under nonsterilized conditions, where microbial breakdown is a factor.

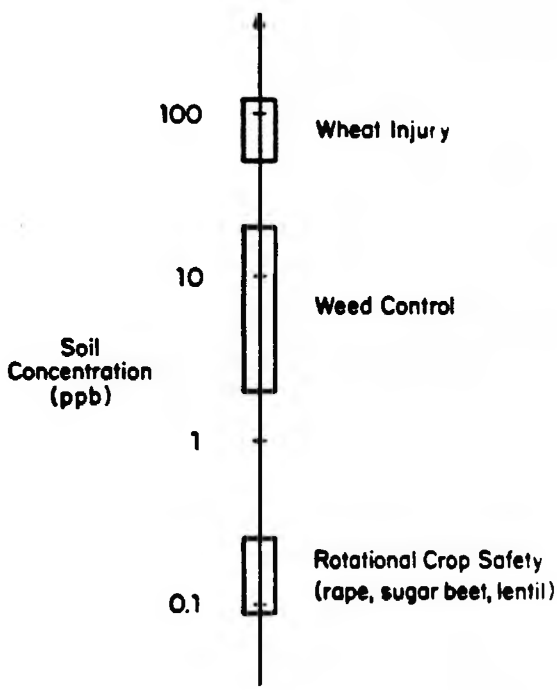


Figure 6. Residual activity for chlorsulfuron.

The Imidazolinone Herbicides

D. Shaner

INTRODUCTION

The name imidazolinone refers to the chemistry of the five-membered ring containing the two nitrogen atoms and carbonyl group. This group, with the methyl/isopropyl substituent, is common for all four imidazolinones currently in use or in development (Figure 1).

HISTORY OF THE IMIDAZOLINONES

The discovery of the imidazolinones began in a random screening test of a compound originally synthesized as a potential anticonvulsant. This compound belonged to a chemical class called the phthalimides (Figure 2). It exhibited sufficient efficacy against broadleaf weeds to encourage chemists to synthesize a number of analogs.

Replacement of a hydrogen on the aromatic ring with a chlorine resulted in a chemical that was devoid of herbicidal activity but had a pronounced growth stimulating effect (Figure 2). This serendipitous discovery led to another synthesis program that resulted in AC 94,377 (Figure 2), the most active growth stimulant in the series.

Due to a large field testing program for AC 94,377, massive quantities of this chemical were prepared. During one of these syntheses, a fortuitous accident occurred. Instead of the reaction stopping at the desired product, water was removed to give a tricyclic compound (Figure 3). This compound behaved similarly to AC 94,377, but was slower acting.

For patent purposes, analogs of this cyclized product were made, including one derived from the original lead compound that started this series (Figure 3). This compound proved to be a very good, broad-spectrum herbicide in the greenhouse, although its field activity did not justify further development.

The first imidazolinone was made when methanol was added to the herbicidally active tricyclic compound (Figure 4). This compound was a very active herbicide with rice tolerance, but was never commercially developed. Imazamethabenz methyl (Assert) (Figure 1), a herbicide for cereals that controls wild oats (*Avena fatua)*, black grass (*Alopecurus myosuroides*), silky bentgrass (*Apera spica-venti*), and cruciferous weeds, was discovered in this synthesis program. A considerable effort was directed toward the development of the benzene imidazolinones, but except for Assert, no more commercial leads were found.

Just as the synthesis effort was winding down, Dr. M. Los began to examine the effect of replacing the benzene ring with a pyridine ring. The result, AC 240,000 was prepared and tested in the greenhouse. At 0.25 lb/A all 12 weed species in the test were killed. This compound eventually led to imazapyr

(Figure 1), the active ingredient in Arsenal, a total vegetation control herbicide. It also started a very fruitful new synthesis program. Two of the compounds to come out of this program were imazaquin and imazethapyr (Figure 1), the active ingredients in Scepter and Pursuit, respectively. Both of these herbicides are selective in soybeans but differ in their weed control spectrums.

Synthesis continues in the imidazolinones and future products should come from this exciting series.

TOXICOLOGY OF THE IMIDAZOLINONES

Extensive toxicology studies have been conducted on the imidazolinones. These herbicides have very low toxicity to mammals, fish, birds, and invertebrates. The oral LD_{50} for all the imidazolinones is >5000 mg/kg body weight in rats, >2150 mg/kg in quail and mallard duck, and >100 µg/bee. They are also classified as nonirritating in the rabbit skin and rabbit eye tests. The imidazolinones were also classified as nonmutagenic and nonteratogenic. In addition, these herbicides are rapidly excreted from animals through the urine and feces and, hence, do not accumulate in the blood or tissues of animals. Studies have also shown that there are no imidazolinone residues in the milk or meat of ruminants or in the eggs or meat of laying hens. Thus, the imidazolinones are safe to nontarget organisms when used as directed.

MODE OF ACTION OF THE IMIDAZOLINONES

Although the four imidazolinones that are in commercial use or in development vary in their weed control spectrum and selectivity, they share the same mechanism of action. The imidazolinones are absorbed by both the foliage and roots of plants and translocate via the xylem and phloem to the growing points where they exert their primary herbicidal action.

These herbicides kill plants by reducing the levels of the amino acids valine, leucine, and isoleucine through the inhibition of the first enzyme common to their biosynthetic pathway. This inhibition disrupts protein synthesis in plants which leads to a cessation of cell division and growth, and eventually results in the death of the whole plant. This biosynthetic pathway exists only in plants, which partially explains the low toxicity of the imidazolinones to animals.

One of the consequences of this mechanism of action of the imidazolinones is the apparent slowness of death of treated weeds. Many weeds do not die completely until 2 to 4 weeks after treatment. Because the growing points of plants have a high demand for amino acids they must synthesize much of their own; hence, these growing points are the sites that are the most sensitive to the imidazolinones. Mature plant tissue, on the other hand, does not have a high demand for amino acids and dies more slowly as it is starved for amino acids. Similarly, germinating seedlings are supplied initially with amino acids from the endosperm. Consequently, imidazolinones do not inhibit germination.

As a result of amino acid inhibition, the first sign of herbicidal activity of the imidazolinones is a cessation of growth. Next follows chlorosis and necrosis of the growing point and then dieback of the rest of the plant. There has been some concern that because treated plants don't die quickly, the weeds are still competing with the crop for nutrients and water. However, research in our laboratories has shown that water usage by treated plants declines rapidly within 2 days after treatment.

Imazapyr

Imazapyr is the active ingredient in Arsenal, Cyanamid's total vegetation control herbicide. This was the first imidazolinone to be registered for use. Although imazapyr controls the broadest spectrum of weeds of all the imidazolinones, it does show selectivity on certain conifers, rubber trees, oil palms, and sugarcane.

Imazapyr controls an extremely broad spectrum of annual and perennial monocots and dicots, including woody perennials. One of the reasons for the effectiveness of imazapyr is its excellent systemic movement within a plant. Over 50 percent of the herbicide absorbed by a leaf will translocate out of that leaf to the rest of the plant. Imazapyr effectively kills perennials by killing the underground reproductive organs such as the rhizomes in Johnsongrass (*Sorghum halepense*) or field bindweed (*Convolvulus arvensis*) roots. Another factor that contributes to the broad spectrum of activity of imazapyr is the inability of most plants to metabolize and detoxify the herbicide.

Imazaquin

Imazaquin is the active ingredient in Scepter, Cyanamid's soybean herbicide that was registered in 1986. Imazaquin can be applied preplant incorporated, preemergence, or postemergence. However, it is most efficacious when applied to the soil and mixed with a grass herbicide such as pendimethalin or alachlor. Imazaquin controls a broad spectrum of broadleaved weeds including cocklebur (*Xanthium strumarium*), pigweeds (*Amaranthus* spp.), velvetleaf (*Abutilon theophrasti*), smartweed (*Polygonum* spp.), and some morningglory species at the low rate of 0.125 lb/A. Imazaquin also controls or reduces the competition of several important grasses and sedges. Based on market share, Scepter is now the most widely used broadleaf herbicide in soybeans in the United States.

The selectivity of imazaquin depends on the ability of the plant to rapidly metabolize the herbicide. The half life of imazaquin in a susceptible weed such as cocklebur is greater than 30 days while in a tolerant plant such as soybeans the half life is less than 3 days. One of the consequences of this type of selectivity is that under adverse conditions, such as excessive rainfall, below normal soil temperatures, or excessively high air temperatures coupled with water-logged soil, soybeans may not be able to rapidly detoxify the herbicide. This results in a slowdown in growth and a shortening of the internodes. However, as soon as conditions return to normal, the crop quickly recovers. Field studies have shown that the shortened internodes have no effect on yield.

Imazethapyr

Imazethapyr is the active ingredient in Pursuit, another of Cyanamid's soybean herbicides. Imazethapyr differs from imazaquin in that it exhibits selectivity to peas, edible beans, peanuts, alfalfa, clover, and other leguminous crops. Imazethapyr controls a broad spectrum of grass and broadleaved weeds including foxtails (*Setaria* spp.), shattercane (*Sorghum bicolor*), jimsonweed (*Datura stramonium*), nightshades (*Solanum* spp.), velvetleaf (*Abutilon theophrasti*), pigweeds (*Amaranthus* spp.) and Jerusalem artichoke (*Helianthus tuberosus*) at rates between 0.063 and 0.094 lb/A. Imazethapyr had an Experimental Use Permit (EUP) in 1987 and full registration is expected in 1989.

Tolerant crops can rapidly detoxify imazethapyr while susceptible weeds cannot. The half life of imazethapyr in soybeans is 1.2 days while its half life in cocklebur and velvetleaf is 20 and 14.5 days, respectively.

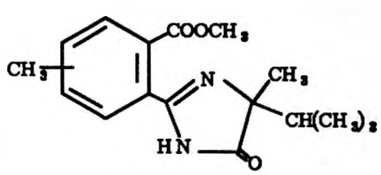
Imazamethabenz methyl

Imazamethabenz methyl is a mixture of two isomers of the active ingredient in Assert. This herbicide is applied postemergent to cereals to control wild oats (*Avena* spp.), blackgrass (*Alopecurus myosuroides*), silky bentgrass (*Apera spica-venti*), and cruciferous weeds.

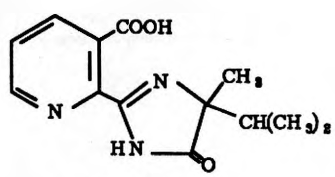
Unlike the other imidazolinones, imazamethabenz methyl is a methyl ester of the active acid form of the herbicide (Figure 1). This special property plays a crucial role in the selectivity of this herbicide. Susceptible weeds rapidly de-esterify imazamethabenz methyl to the active acid form of the herbicide. This acid then translocates to the growing points of the plant where it inhibits cell growth. Tolerant cereals metabolize imazamethabenz methyl to other nontoxic metabolites and do not form high levels of the active acid. Like the other imidazolinones, imazamethabenz methyl kills susceptible weeds slowly, although the competitiveness of the weeds stops soon after treatment.

FIGURE 1

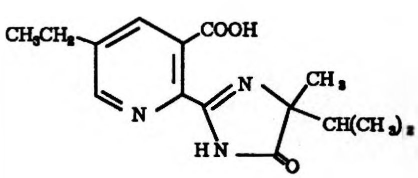
STRUCTURE OF IMIDAZOLINONES



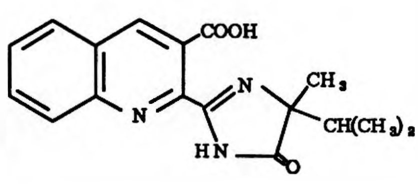
IMAZAMETHABENZ METHYL



IMAZAPYR

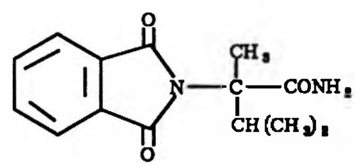


IMAZETHAPYR

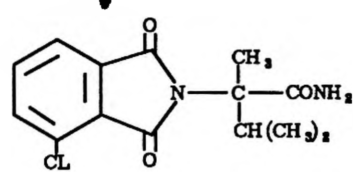


IMAZAQUIN

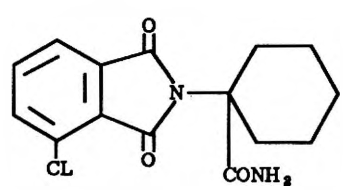
FIGURE 2



ORIGINAL PHTHALIMIDE
TESTED 1969
KILLED 4 BROADLEAVES AND NUTSEDGE

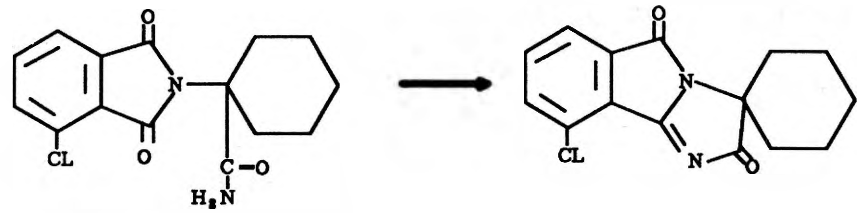


FIRST PHTHALIMIDE PGR
GROWTH STIMULATOR



AC 94,377

FIGURE 3

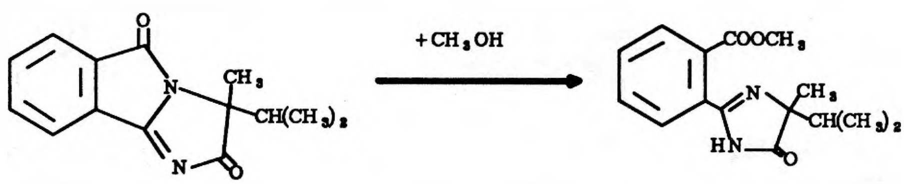


CYCLIZED PRODUCT OF AC 94,377

1974 HERBICIDE

CYCLIZED PRODUCT OF ORIGINAL LEAD

FIGURE 4



FIRST IMIDAZOLINONE FROM TRICYCLIC COMPOUND

Herbicide Persistence--Where and Why

R. Liebl and M. Loux

The ideal soil-applied herbicide would persist in soil long enough to provide adequate weed control during the season of application, but not so long that soil residues would injure subsequent rotation crops or contaminate groundwater. Unfortunately, herbicide breakdown is not a fixed property of the herbicide molecule, but is influenced by soil type, climate, tillage practices, etc., and is, therefore, not easy to predict.

Herbicide dissipation in the soil results from a combination of degradation and transfer processes. Degradation is defined as the process by which a herbicide is structurally altered through chemical, photochemical, and microbial means. Transfer processes include volatilization, leaching, and surface runoff. The magnitude of these processes is further influenced by soil, weather, and cropping conditions that together determine the persistence of a herbicide in soil.

FACTORS AFFECTING HERBICIDE DISSIPATION

Soil type and organic matter. The influence of soil type on herbicide persistence is not well understood. In general, herbicide persistence tends to increase with increasing clay and organic matter in the soil. Increased persistence is attributable to the high affinity herbicide molecules have for these soil constituents. However, herbicide degradation can be more rapid in soils with higher organic matter due to the greater microbial activity in these soils. Organic matter supports the soil microbial population, so increased soil organic matter content may increase degradation rates of herbicides for which microbial degradation is important. The influence of organic matter on herbicide dissipation will depend on the degree of herbicide adsorption to organic matter and the influence of microbial degradation. A herbicide that is not readily degraded by soil microbes but has a high affinity for organic matter will likely persist in high organic matter soils.

Soil pH. pH can affect herbicide dissipation directly if the stability of the herbicide is pH-dependent, or indirectly via its effect on microflora and adsorption. The stability of Classic and atrazine, for example, are pH-dependent. These two herbicides break down in soils with low pH, but are very stable and persistent at high pH.

Soil water and temperature. The effects of soil water and temperature on herbicide degradation are primarily indirect in that they regulate microbial activity. While conditions required for optimum microbial activity are not the same for all species, the activity of many species is greater at water contents between 50 and 75 percent of field capacity and temperatures between 75^{o}F and 95^{o}F.

Soil moisture can also affect herbicide persistence by altering the availability of herbicides to microbes that degrade them. As soil water decreases, the equilibrium that exists between herbicide adsorbed to soil and herbicide in the soil solution shifts to favor adsorption. Herbicide molecules adsorbed to soil particles are less likely to be degraded by microbes than those molecules in the soil solution.

Tillage practices. Tillage may be a relatively easy way to enhance herbicide detoxification. Cultivation that brings the herbicide to the soil surface can help to detoxify herbicides by allowing for loss via photodecomposition and volatilization. Deep plowing can remove phytotoxic residues from the areas of germination and seedling development.

The method of application can also influence the residual activity in soil. In general, herbicide persistence is increased when herbicides are applied preplant incorporated as opposed to a surface-only application. Incorporation of a herbicide partially eliminates photodegradation and volatilization losses.

PERSISTENCE VERSUS BIOAVAILABILITY

Just because a herbicide is found to persist (detection by chemical extraction) to the following cropping season, it does not necessarily mean that the herbicide will injure sensitive rotation crops. As mentioned earlier, many herbicides bind strongly to organic matter and clay fractions in the soil. Herbicides are generally much less susceptible to microbial breakdown and less available to uptake by plants when adsorbed to soil. Therefore, the fraction of herbicide molecules adsorbed to organic matter and clay, although likely to be more persistent, may represent a less biologically active form of the herbicide.

REASON FOR CURRENT INTEREST IN HERBICIDE PERSISTENCE

Concern about herbicide persistence and potential carryover resulting in rotation crop injury has been brought to the forefront of the weed science community's attention by the recent introduction of three new soybean herbicides. These herbicides are Scepter, Command, and chlorimuron, the active ingredient in Classic and one of the components in Preview herbicide. All three herbicides are expected to have great impact on soybean weed control programs in Illinois. However, preliminary studies have demonstrated that these compounds have relatively long residual activity in certain soils. This persistence, coupled with corn susceptibility, has occasionally resulted in the appearance of herbicide injury symptoms on corn plants in plots treated with these herbicides the previous season. Presently, university and industry researchers are attempting to obtain a better understanding of the dissipation of these herbicides in soil. Knowledge of the factors controlling herbicide breakdown will allow us to better manage their use by developing programs that minimize extended persistence while maintaining adequate weed control.

Crop Tolerance and Carryover Concerns with Scepter, Pursuit, Command, and Chlorimuron: Results of Field Studies in Northern and Central Illinois

W. Curran and E. Knake

Several new soybean herbicides were recently introduced for use in Illinois. These herbicides include imazaquin (Scepter), clomazone (Command), and chlorimuron (Classic and a component of Preview and Lorox Plus). Additionally, American Cyanamid is developing a close relative of imazaquin called imazethapyr (Pursuit) that should be available for use in soybeans in 1989. All four of these herbicides are active in soil and potentially persist and injure sensitive rotational crops. Proper herbicide management is necessary to prevent rotational crop injury and insure a clean environment. Rotational crop restrictions are present on all herbicide labels and should be followed closely (Table 1).

Research conducted at the University of Illinois has focused on the length of time necessary for these new soybean herbicides to degrade and not injure sensitive crops. Studies conducted at the University of Illinois determined that clomazone, imazaquin, and imazethapyr are all more likely to carryover on soils that are fine-textured and higher in organic matter content (See *Illinois Agricultural Pesticide Conference '87: Summaries of Presentations*, pp. 154-155). This is more typical of the soils found in central and northern Illinois. Other studies show chlorimuron may persist for long periods of time in soil with a pH greater than 6.8. Soil with a pH below 6.8 is less likely to have carryover problems with chlorimuron.

In studies conducted in 1986 and 1987 we examined several rates of imazaquin, imazethapyr, clomazone, and chlorimuron at three different locations in central and northern Illinois. Herbicides were surface applied in 1986 at up to two or three times the normal rates used in soybeans near Urbana, DeKalb, and Monmouth, Illinois. Locations at Urbana and DeKalb were on Drummer silty clay loams with approximately 6.0 percent organic matter and soil pH of 6.2 and 6.0, respectively. The Monmouth location was on a Muscatine silt loam with 4.5 percent organic matter and a soil pH of 7.2. The high herbicide rates were to simulate a misapplication such as sprayer overlap or a poorly-calibrated spraying system. Soybeans were grown in 1986 and evaluated for crop tolerance and yield.

In 1987, Pioneer 3377 corn was planted no-till at all three locations into the plots treated in 1986. The corn crop was evaluated for plant emergence and stand, early and late season visual injury, early and late season plant height, seedling dry weight, stalk diameter, and grain yield. Visual injury ratings were expressed as a percent bleaching or "whiteness" for clomazone and percent stunting and/or chlorosis for imazaquin, imazethapyr, and chlorimuron. The study is being repeated in the 1987-88 rotational season.

At Urbana, early season corn injury was moderate with clomazone, averaging 39 percent and occasional plant death from the 2.0 lb/A rate. Other locations showed little visual injury from clomazone and by mid-season, corn had almost completely recovered at all locations. Imazaquin injury was slight at all three locations. Corn seedling dry weight and height were both slightly depressed at

Urbana and DeKalb, but by mid-season the crop had recovered. Imazethapyr injury was not a problem at any location. At the highest rate, early season chlorimuron injury was slight at Urbana and DeKalb and moderate at Monmouth as indicated by visual injury, seedling dry weight, and seedling plant height. By mid-season, corn at Urbana and DeKalb showed recovery, while at the Monmouth location, both visual ratings and plant height measurements indicated significant crop injury at the two highest rates of chlorimuron. The high soil pH at the Monmouth location probably prolonged the persistence of chlorimuron.

Using the check plots for comparison, there was no statistically significant corn yield reduction at any location.

These results suggest that the likelihood of recovery from early season corn injury is good for clomazone, imazaquin, imazethapyr, and chlorimuron. At all three locations corn recovered without suffering a significant yield loss. However, this does not preclude the possibility of sufficient effects from these herbicides under certain conditions to affect yields in some fields. In addition, this study does not indicate the possible additive effects of herbicides used in combination or possible additive effects from continued use for several years.

Environmental conditions throughout the year will greatly affect herbicide persistence and availability to plants. Factors such as soil moisture and temperature determine how quickly herbicides degrade and whether the chemical is available for plant uptake. If soil moisture is low at planting time and throughout early crop development, herbicide availability and uptake by the crop may be limited. At all three locations, soil moisture was low at planting time and for 20 to 30 days thereafter. This may have allowed the corn seedlings to grow through the herbicide-treated soil zone with little herbicide uptake. When additional rainfall did occur, the corn roots were outside the treated zone and able to take advantage of additional soil moisture. It should be stressed that these results represent only one rotational season. Environmental conditions in other years may produce different results.

Table 1. Recrop Restrictions for Clomazone, Imazaquin, and Chlorimuron

	Crop		
Herbicide	Field Corn[a]	Wheat	Alfalfa
	Time interval to replanting (months)		
Chlorimuron			
Classic	9	3	--[b]
Preview	10	4	10
Lorox Plus	10	4	--[b]
Clomazone	9	--[c]	--[c]
Imazaquin	11	4	18

NOTE: Refer to most recent labels for specifics and current restrictions.
[a]Additional restrictions may apply for corn produced for seed.
[b]Must conduct a successful field bioassay (see label).
[c]Do not plant in fall of the year of application or in spring of following year.

Table 2. Effect of Clomazone, Imazaquin, Imazethapyr, and Chlorimuron on Rotational Corn at Urbana, DeKalb, and Monmouth

Herbicide	Rate (lb/A)	Urbana Early injury (%)	Urbana Grain yield (bu/A)	DeKalb Early injury (%)	DeKalb Grain yield (bu/A)	Monmouth Early injury (%)	Monmouth Grain yield (bu/A)
Clomazone	1.0	6	211	2	164	0	180
Clomazone	2.0	39[a]	209	4[a]	166	0	186
Imazaquin	0.125	0	212	1	163	1	183
Imazaquin	0.25	0	208	2	159	1	182
Imazethapyr	0.094	0	214	0	166	0	175
Imazethapyr	0.188	0	209	1	159	0	184
Chlorimuron	0.031	3	213	1	162	1	177
Chlorimuron	0.094	0	211	5[a]	160	12[a]	173
Check	0.0	0	213	0	164	0	179
LSD	(0.05)	8	8.4	3	8.5	3	10.8

[a]Signifies a significant difference from the check.

Table 3. Key to Herbicide Common Names

Common name	Tradename
Clomazone	Command
Imazaquin	Scepter
Imazethapyr	Pursuit
Chlorimuron	Classic
Chlorimuron + Metribuzin	Preview
Chlorimuron + Linuron	Lorox Plus

Crop Tolerance and Carryover Concerns with Scepter, Pursuit, Command, and Chlorimuron: Results of Field Studies in Southern Illinois

R. Krausz and G. Kapusta

Most soil-applied soybean broadleaf herbicides used in past years for soybeans, such as Lexone, Sencor, Lorox, and Amiben, have relatively short soil persistence and generally have not presented a carryover problem for rotational crops. By contrast, the new generation of herbicides, such as Command, Scepter, Pursuit, and chlorimuron (one of the components of Preview and Lorox Plus), are characterized by a substantially longer soil life. Although this may be desirable to maintain season-long weed control in the soybeans, excessive persistence that may cause injury or even stand reduction to susceptible rotational crops should be avoided. Soybean tolerance to new herbicides is also a concern.

Studies were initiated in 1984 to obtain information on soybean tolerance to these new herbicides and to determine if they posed a carryover problem to rotational crops. These studies were conducted at the Southern Illinois University Belleville Research Center on a silt loam soil with 1.0 to 2.0 percent organic matter and a pH between 6.2 and 6.7. Precipitation averages 39 inches per year with 26 inches occurring from April through October. All studies were located on relatively level land with poor internal and surface drainage. All plots were kept weed-free throughout the season with a combination of herbicides, mechanical cultivation, and hand weeding to obtain information on the influence of the herbicide on a weed-free crop (Table 1).

SOYBEAN TOLERANCE, 1984-1987

Command, Scepter, and chlorimuron had no significant influence on soybean yield in two studies in 1984 and one in 1985. Yields from the 1985 study followed two consecutive years of application of these herbicides. Although there were some numerical differences, especially in Study II in 1984, these differences were not statistically significant.

Another study was initiated in 1986 to evaluate soybean tolerance to Command, Scepter, Pursuit (an experimental herbicide related to Scepter), and chlorimuron applied at rates up to three-times that which was suggested on the label. The chlorimuron rates selected were based on the approximate amount of this herbicide in Preview and Lorox Plus. Yields from these plots were compared to those treated postemergence with Basagran at 1 pint per acre (pt/A), plus Blazer at 1 pt/A, plus crop oil concentrate at 1 quart per acre (qt/A). The maximum product rates evaluated were Command 4EC at 6 pt/A, Scepter 1.5AS at 32 oz/A, Pursuit 2AS at 18 oz/A, and Classic 25DF at 8 oz/A (equal to 30.8 oz/A of Preview 75DF).

In plots treated with up to three-times the suggested rates of these herbicides, soybean yields were equal to or greater than those obtained where Basagran plus Blazer was used (Table 2). There was no visible injury apparent with any of the herbicides, and soybean height and populations were not affected (data not presented). This study was repeated in 1987, again with no evidence of soybean injury or differences in height or population. These results indicate the relatively high level of tolerance of soybeans to these new soil-applied herbicides.

TOLERANCE OF WHEAT, GRAIN SORGHUM, AND CORN

One of the plot areas treated in 1984 with Command, Scepter, chlorimuron, and Lasso was recropped to corn in 1985. There was no difference in corn yield among the several treatments in 1985 (Table 3). Results from the Command plots were not obtained that year. Half of the study area was treated with the same herbicides (the second consecutive year) and again planted to soybeans. Following soybean harvest, wheat was planted in October of 1985, and corn and grain sorghum in 1986. Yield data from the rotational crops (following two consecutive years of these herbicides) is presented in Table 3. There were no differences in the yield of any of the rotational crops among the several herbicide treatments.

An even more comprehensive study was initiated in 1986 to evaluate the tolerance of rotational crops to Command, Scepter, Pursuit, and chlorimuron. Rates of these herbicides ranged from one-half to three-times that of current label suggestions. Table 4 presents 1987 wheat yields following the 1986 application of the herbicides. Again, there were no differences in wheat yield regardless of the herbicide or rate used. Although numerical differences occurred, these simply represent normal variations in the field.

Corn was planted in May of 1987 on a portion of the plots treated with up to three times the label rates of these four herbicides. Population counts in June indicated no influence from the preceding herbicide treatment on corn stand. Visual observations indicated no evidence of corn injury at any time during 1987. Yields are presented in Table 4.

DISCUSSION

Results from studies conducted from 1984 through 1987 indicate that soybeans tolerated up to three-times the label rate without any visible injury or influence on yield through 1987 with Command, Scepter, and chlorimuron, and with Pursuit in 1986 and 1987.

The rotational crops--wheat, grain sorghum, and corn--also exhibited no visible injury or yield reduction from these herbicides in these studies. These results do not necessarily assure growers that injury or yield reduction will not occur. However, under the conditions of this study, soybeans had considerable tolerance and very little herbicide injury on the rotational crops was indicated. Herbicide carryover to rotational crops rarely has been a problem in southern Illinois, even with relatively long residual herbicides such as simazine and trifluralin. The low organic matter soils prevalent in this area allow for the use of lower herbicide rates than needed on high organic matter soils. Further, the affinity of the herbicides to the soil is lower due to the low organic matter content, promoting more rapid breakdown. In addition, southern Illinois is characterized by a relatively long breakdown season and high precipitation and temperatures--factors that favor rapid herbicide breakdown.

Although we should not preclude the possibility of problems in some fields, our data thus far suggests that soybeans generally have relatively good tolerance to these herbicides. Additionally, carryover to rotational crops may not be a serious problem in southern Illinois when these herbicides are applied accurately and uniformly at appropriate rates.

Table 1. Soybean Tolerance to Alachlor, Clomazone, Imazaquin, and Chlorimuron, Belleville, 1984-85

Herbicide[a]	Rate (lb a.i./A)	Study I 1984[b]	Study II 1984[c]	1985[b]
		-----------*yield, bu/A*[d]	-----------	
Alachlor	2.0	38	43	23
Clomazone	1.0	39	40	22
Imazaquin	0.25	39	36	23
Chlorimuron	0.03	41	40	23

[a]Trade names and product rates are: Alachlor = Lasso 4MT at 2 qt/A; Clomazone = Command 4EC at 1 qt/A; Imazaquin = Scepter 1.5 AS at 1.3 pt or 21 oz/A; and, Chlorimuron = Classic 25DF at 0.125 lb or 2 oz/A (equal to approximately 8 oz/A Preview 75DF).
[b]Herbicides applied in 1984 only.
[c]Herbicides applied in 1984 and 1985.
[d]Differences in yield within columns are not significant.

Table 2. ***Influence of Clomazone, Imazaquin, Imazethapyr, and Chlorimuron on Soybean Yield, Belleville,*** **1986**

	Lowest	Herbicide rate[a]			Highest
Herbicide	I	II	III	IV	V
	soybean yield, bu/A[b]				
Bentazon + acifluorfen + COC[c]	40 c				
Clomazone	41 bc	41 abc	42 abc	47 ab38 c	38 c
Imazaquin	42 bc	43 abc	41 c	47 ab	43 abc
Imazethapyr	40 c	42 abc	41 bc	42 abc	46 ab
Chlorimuron	42 abc	41 bc	44 abc	47 a	44 abc

[a]Herbicide rates evaluated as follows (expressed as lb a.i./A):

Clomazone	0.5	0.75	1.0	2.0	3.0
Imazaquin	0.06	0.125	0.188	0.25	0.375
Imazethapyr	0.047	0.093	0.125	0.188	0.281
Chlorimuron	0.021	0.042	0.063	0.083	0.125

[a]Herbicide rates evaluated as follows by trade name (expressed as product rate per acre):

Command 4EC (pt/A)	1.0	1.5	2.0	4.0	6.0
Scepter 1.5AS (oz/A)	5.3	10.7	16.0	21.3	32.0
Pursuit 2AS (oz/A)	3.0	6.0	8.0	12.0	18.0
Classic 25DF (oz/A)	1.33	2.66	4.0	5.33	8.0

[b]Values within or between columns followed by one or more like letters are not different at 5 percent.
[c]Bentazon at 0.5 lb a.i./A (Basagran at 1.0 pt/A), acifluorfen at 0.25 lb a.i./A (Blazer at 1.0 pt/A), and crop oil concentrate at 1.0 qt/A.
[d]Preview 75DF rates in oz/A that would contain an equivalent amount of chlorimuron are 5.1, 10.3, 15.4, 20.5, and 30.8.

Table 3. Rotational Crop Yield Following the Application of Alachlor, Clomazone, Imazaquin, and Chlorimuron, Belleville

Herbicide[a]	Rate lb a.i./A	1985 Corn[b]	1986[c] Wheat	1986[c] Corn	1986[c] Sorghum
		yield, bu/A[d]			
Alachlor	2.0	198	69	170	115
Clomazone	1.0	...	71	186	106
Imazaquin	0.25	199	67	177	116
Chlorimuron	0.03	199	74	193	118

[a]Trade names and product rates are: Alachlor = Lasso 4MT at 2 qt/A; Clomazone = Command 4EC at 1 qt/A; Imazaquin = Scepter 1.5 AS at 1.31 pt or 23 oz/A; and, Chlorimuron = Classic 25DF at 0.125 lb or 2 oz/A (equal to approximately 8 oz/A Preview 75DF).
[b]The herbicides listed were applied to soybeans in 1984.
[c]The herbicides listed were applied in 1984 and 1985 to soybeans prior to planting the rotational crops.
[d]Differences in yield within columns are not significant.

Table 4. Influence of 1986 Applied Clomazone, Imazaquin, Imazethapyr, and Chlorimuron on 1987 Wheat and Corn Yields, Belleville

Herbicide	Lowest I	II	Herbicide rate[a] III	IV	Highest V
	wheat yield, bu/A[b]				
Bentazon + acifluorfen + COC	65				
Clomazone	67	71	72	73	71
Imazaquin	70	68	68	69	69
Imazethapyr	75	74	78	71	74
Chlorimuron	70	77	77	72	71
	corn yield, bu/A[b]				
Bentazon + acifluorfen + COC	165				
Clomazone	168	175	172	169	187
Imazaquin	177	173	169	176	168
Imazethapyr	176	171	175	177	183
Chlorimuron	176	182	174	177	180

[a]See Table 2 for rates of each herbicide expressed in lb a.i./A or product rate listed by trade name.
[b]No significant difference in yield between any of the treatments.

Assessing Herbicide Residue in Soil, Water, and Plants

D. Pike

With the recent introduction of several new herbicides representing new classes of chemical compounds, farmers are more concerned than ever about crop tolerance, carryover effects, and movement of herbicides into groundwater. Many farmers have expressed the opinion that these problems have become worse in the last few years and that the herbicides are to blame. A review of the situations associated with complaints often indicates otherwise.

Requests for diagnosis of potential herbicide injury to crops constitutes a large number of complaints. While it is generally assumed that crops to which herbicides are applied have relatively good tolerance to newer herbicides, the relationship between crop varietal tolerance, climatic conditions, and field management is not always well understood. In addition, the effects of combinations of many herbicides on crop tolerance or carryover potential have not been thoroughly investigated. However, careful investigation of symptoms as they appear in the field is useful in characterizing the causes of poor plant growth.

The first step in determining if a plant has been injured by a herbicide is to determine if the symptoms are characteristic of that compound. Visual descriptions and photographs of herbicide injury are available in numerous publications. Although the "textbook" case may seldom be seen under average field conditions, the appearance will be similar. Cool damp weather associated with early planting may result in symptoms similar to herbicide injury and can easily worsen true herbicide injury symptoms. If most plants throughout the field are injured, yet weeds which are known to be susceptible to the suspected herbicide are not completely controlled, it is doubtful that herbicide injury is involved.

Because weeds often show herbicide injury symptoms similar to crop plants, they are good indicators of herbicide problems. Similarly, weeds that are tolerant of herbicides may also provide clues to diagnosis. Injury symptoms that occur sporadically within a field may indicate poor herbicide distribution. This problem has increased greatly in the last few years where farmers reduce the number of incorporation passes and till the soil when it is too wet. Poor incorporation can result in high concentrations of a herbicide in spots. Although patterns in the field representing tillage tool movement can sometimes be observed, the symptoms more often appear random. Professional diagnosis of injury can be obtained by submitting plant samples to the University of Illinois Plant Clinic at 1401 St. Mary's Road, Urbana, 61801. See your county Extension adviser for submission forms and advice regarding sample preparation.
A number of the preceding concepts apply to carryover of herbicides to susceptible crops in the year following application. However, two new concerns also arise. The first is climatic conditions late in the crop season and in the fall and spring. Dry hot weather or very cool, wet weather reduces the microbial and chemical breakdown of most herbicides, resulting in more of the herbicide in the soil at the time a subsequent crop is planted.

The second concern is soil drainage. Slow water percolation due to compacted or fine-textured soils can cause a high concentration of a herbicide to be retained in the area just above the plow pan or clay layer. This concentrated layer of herbicide may prove to be a barrier to crop roots trying to penetrate to lower depths and may result in stunted root growth. Stunted root growth can result in smaller plants and yield reductions.

Under such conditions, deep tillage may alleviate the problem by diluting the herbicide more thoroughly in the rooting zone. Where carryover is a significant concern, delaying planting of the crop might be considered to permit additional breakdown of the herbicide. Planting delays can also favor the crop because warmer weather may help the plants outgrow early injury.

Growers wishing to assess the amount of carryover can conduct a bioassay with susceptible crop species or submit soil samples to testing labs. A fee schedule for some of the more commonly used testing labs--A & L Great Lakes (219)456-3545, Harris Laboratories Inc. (800)228-4091, Centralia Animal Toxicology Lab (618)532-6701--can be obtained by telephone. It is always a good idea to call prior to submitting a sample to check on sample backlogs and expected turnaround times. Bioassay and sampling techniques and descriptions on how to interpret results are published in the *Illinois Agricultural Pesticide Conference Handbook*.

The popular press has recently drawn much attention to the question of herbicide movement to groundwater. Because many farm families drink water from shallow wells, the concern is very acute. Although numerous samplings of wells in the state have indicated that pesticide movement can be a problem in areas of shallow groundwater, sandy soils, or karst topography, seldom are significant concentrations found in the majority of wells. Although the University of Illinois does not test well water, a number of testing labs will do so on a fee-basis. This can be an expensive procedure, depending on the number of pesticides tested for. However, if growers suspect backsiphoning or pesticide spills affecting the well, the services of the Illinois Environmental Protection Agency (EPA), the Illinois Department of Agriculture, or the Department of Public Health can be used to identify well contamination.

Genetic Differences in Herbicide Tolerance

L. Paul

When evaluating a new herbicide, chemical companies must be aware of more than product effectiveness. They must also consider the effect of the herbicide on the crop that will be grown in the following year. When evaluating herbicides for soybeans in the Corn Belt, it is likely that corn will be planted in the treated field the following year. This means that good corn tolerance and low levels of herbicide carryover are important.

There is concern that some of the new soybean herbicides may stay in the soil and carry over to the next year. How much will carry over into the following year is a critical concern and makes knowledge of genetic differences in crop tolerance between hybrids important.

The fact that there are differences in the response of corn hybrids to herbicides has been known for many years. DeKalb AgResearch Inc., in a pronounced example of a genetic difference to a herbicide, put a red tag on the bags of one of their hybrids that indicated that it was not to be used with Eradicane. This particular hybrid reacted with Eradicane to form a plant that resembled a bush with only a rosette of leaves. Fortunately, this type of pronounced crop reaction is not common.

In greenhouse work, ten corn hybrids were evaluated for their response to Scepter, Pursuit, Classic, and Command. The rates applied were about one-fourth and one-half the normal soybean application rate for Scepter, Pursuit, and Classic and about one-half the normal rate for Command. Root growth reduction after ten days was 21 percent to 64 percent depending on the hybrid involved and the chemical applied. For example, when Scepter was applied at one-half the normal rate, Pioneer hybrid 3320 had a 64 percent reduction in root weight while Pioneer hybrid 3358 had a 36 percent reduction at the same application rate. Shoot growth was reduced with Command applications from 0 to 44 percent.

In the summer of 1987, there were several studies conducted in Illinois to evaluate carryover problems with the new soybean herbicides. Three of these studies were conducted at the Northern Illinois Agronomy Research Center near DeKalb. In one of those studies, there were four application rates each of Classic, Command, Pursuit, and Scepter applied and incorporated prior to planting. Lasso and Aatrex were applied as a check treatment. After herbicide application, ten hybrids and eighteen inbred lines were planted into the treated field.

Because inbred lines are weaker in vigor, they are more likely to be susceptible to injury than are hybrids. This susceptibility was indicated with visual injury ratings as high as 20 to 30 percent on some of the inbred lines, while the average injury to hybrids was 9 percent (Table 1). There were definite differences in the tolerances of the various hybrids to the different herbicides. In this study, no single hybrid was most susceptible to, or most tolerant of, all herbicides.

As a measure of corn plant growth, extended leaf heights were taken at four weeks of growth and compared with the check (Table 2). Some hybrids exhibited plant growth reduction that continued throughout the season and resulted in severely stunted plants at the end of the season. Some of the plants were less than three feet tall and had no ear at first frost. Some of the stunted plants were grass-like in appearance with very narrow and tightly wrapped leaves. The white color typical of Command injury was obvious with the highest rate of Command at two weeks after planting, but had disappeared two weeks later.

Wide variations in plant population reductions were also observed (Table 3). Stand reductions varied from 0 to nearly 100 percent depending on the hybrid/inbred and the herbicide.

Looking at the ten hybrids, it is apparent that more work needs to be done to evaluate differences between hybrids that are marketed in the Corn Belt. Much of this work will be a basic determination of the amount of chemical that is likely to carry over into the next year under the various conditions of soil pH, soil type, and weather. When we have a better idea of the amount of carryover that may be present, the seed companies will need to evaluate their hybrids for crop tolerance. Significant differences need to be reported to the farmers that are buying their products. Farmers can then better evaluate their selection of herbicides and hybrids if reliable information is provided to them.

Table 1. Visual Injury Rating at Four Weeks

Brand		DeKalb Pfizer		Hughes Hybrid		Pioneer Hybrid					
		Injury									
Variety		DK572	DK636	5404	5870	3377	3475	3540	3615	3732	3737
Herbicide	Rate lb a.i./A										
		percentage									
Classic	.0203	0	6	0	0	2	0	0	1	7	0
Classic	.010	1	0	2	2	1	2	1	0	0	0
Classic	.005	0	0	0	0	0	0	0	0	1	1
Classic	.0025	2	1	1	0	0	0	1	1	0	0
Command	.5	4	7	4	1	1	2	1	2	1	2
Command	.25	1	1	1	0	0	0	0	0	1	2
Command	.125	0	0	0	0	0	0	0	0	0	0
Command	.0625	0	0	0	0	0	0	0	0	1	0
Pursuit	.047	2	2	0	3	4	1	3	3	2	4
Pursuit	.023	0	0	2	0	0	2	0	1	0	1
Pursuit	.0117	0	1	1	0	1	2	0	1	0	1
Pursuit	.0058	1	0	0	0	0	0	0	1	0	0
Scepter	.0625	1	9	0	2	2	4	6	2	6	4
Scepter	.0312	0	1	0	0	0	0	1	1	0	1
Scepter	.0156	0	0	0	0	0	0	0	0	0	0
Scepter	.0079	0	0	0	0	0	0	0	1	0	0
LSD	.05	3	8	2	3	3	3	4	2	6	4

Table 2. Extended Leaf Height Growth Rating at Four Weeks

		Height compared to check									
Brand		DeKalb Pfizer		Hughes Hybrid		Pioneer Hybrid					
Variety		DK572	DK636	5404	5870	3377	3475	3540	3615	3732	3737
Herbicide	Rate lb a.i./A										
		percentage									
Classic	.0203	94	88	95	92	91	96	88	93	78	87
Classic	.010	95	101	96	95	100	90	91	98	98	98
Classic	.005	102	100	96	94	101	99	89	95	99	96
Classic	.0025	102	96	102	93	102	102	94	94	104	104
Command	.5	98	96	98	95	100	99	93	100	102	100
Command	.25	100	98	100	98	107	103	98	99	103	104
Command	.125	100	99	102	88	104	99	98	99	102	104
Command	.0625	99	103	101	98	103	97	95	98	105	98
Pursuit	.047	94	83	100	92	87	91	91	89	92	95
Pursuit	.023	101	97	94	98	102	95	93	92	99	97
Pursuit	.0117	100	104	97	96	107	99	97	97	106	102
Pursuit	.0058	95	104	102	96	100	100	95	99	99	96
Scepter	.0625	85	79	89	91	95	85	80	89	90	92
Scepter	.0312	95	96	92	90	96	91	89	94	96	97
Scepter	.0156	100	101	96	99	105	95	95	98	106	91
Scepter	.0079	101	104	107	94	105	99	97	101	105	106

Table 3. Population at Four Weeks

		Stand compared to check									
Brand		DeKalb	Pfizer	Hughes	Hybrid	Pioneer Hybrid					
Variety		DK572	DK636	5404	5870	3377	3475	3540	3615	3732	3737
Herbicide	Rate lb a.i./A										
		percentage									
Classic	.0203	98	98	83	100	96	102	96	97	89	98
Classic	.010	93	98	91	93	93	102	94	88	95	98
Classic	.005	103	100	93	98	107	103	105	102	99	104
Classic	.0025	100	109	84	91	102	105	100	96	87	99
Command	.5	82	85	71	91	89	92	101	89	86	103
Command	.25	100	100	85	109	104	98	100	95	99	105
Command	.125	101	102	87	93	93	109	96	93	87	106
Command	.0625	99	94	87	98	102	107	98	99	94	95
Pursuit	.047	91	86	55	93	89	98	68	95	81	98
Pursuit	.023	103	93	88	92	102	108	96	96	95	97
Pursuit	.0117	98	96	103	96	107	90	98	91	90	106
Pursuit	.0058	107	105	97	114	100	112	98	93	100	105
Scepter	.0625	98	87	96	89	84	100	87	94	88	101
Scepter	.0312	108	96	87	104	107	103	94	104	94	105
Scepter	.0156	100	95	87	96	93	103	100	96	95	88
Scepter	.0079	102	98	101	96	102	110	98	96	90	101

A 40-Year Perspective of the "Spray School"

H. Petty

WHY

The Need. DDT, 2,4-D, toxaphene, chlordane, and BHC were the early pesticides. Fly-by-night, itinerant applicators appeared, but there were also legitimate applicators who were local businessmen. Temporary, overzealous, quick-buck salesmen sprung up, but there were also sincere, honest salesmen. Some salesmen were frightening farmers into treating cornfields for European corn borers in early June when the corn was only a foot tall and egg masses were not yet present. These salesmen often came in with a truckload of DDT dust and an airplane. Local applicators turned down jobs, but the itinerants fast-talked farmers into treatment. Salesmen often assured audiences that 2,4-D could be sprayed in any amounts on any crops without crop damage and with complete weed kill.

These situations encouraged us to hold the first Illinois Custom Spray Operators Training School January 12 to 14, 1949.

WHO

The People. County agricultural Extension advisers were constantly requesting our presence in their counties to combat the aforementioned situations. Legitimate ground spray applicators such as Earl Davies, Vernon Anderson, Robert Hall, Les Carr, and John Pool; aerial applicators like Robert Ueding, Robert Kirkpatrick, Don Rickard, Virgil Helgen, Merle Stinnett, and Lillard Hedden; and chemical salesmen like Dean Roy, Weldon Wadleigh, Robert Rider, and many others promised to support a "University Spray School" as a stabilizing influence for what appeared to be a rapidly expanding and important cog in the future of Illinois agriculture.

HOW

Our county agricultural Extension advisers (a bulwark of support ever since) enthusiastically compiled lists of applicators in their counties, and, in turn, we compiled a mailing list for such a conference. With the help of such staff members as J.H. Bigger, B.J. Butler, G.C. Decker, Lyman Nordhoff, Fred Slife, W.O. Scott, and others, we plunged ahead. (As years went by other staff members like Steve Moore, who was chairman of the school for 12 years, Earle Spurrier, Ellery Knake, Marshal McGlamery, Wendell Bowers, Loren Bode, Don Kuhlman, Roscoe Randell, Kevin Steffey (current chairman), and many more have been mainstays. Now, 40 years later, we are witnesses to the results.)

The weather on January 12, 1949, proved to be typical--spitting snow with a cold wind. Only 125 people preregistered but 359 showed up. This necessitated a move to another building, a condemned auditorium, which upset the fire marshal and some of the attendees. The next day we moved to the University of Illinois airport.

The formation of the Illinois Association of Aerial Applicators and the Illinois Commercial Ground Applicators Association in 1949 proved to be an important adjunct to the Spray School. These trade associations added respectability to the business, discouraged fast-buck operators, and legitimized custom application. Both associations were to help develop our program and guide our thinking.

WHAT

What's New. Research results and new developments were, and continue to be, annual topics. Keeping up-to-date on research in agriculture has always been paramount.

In 1949, F.W. Slife presented, "New Chemicals for Weed Control"; in 1988, Ellery Knake presents, "Some Highlights of Weed Science Research in 1987." In 1949, Carl J. Weinman talked about "New Insecticides, Their Use and Limitations." Presenting the latest information about pesticides and how to use them properly have been important objectives of all 40 schools.

Pesticide Toxicity. In 1949, Roger Link reviewed the "Toxicity of Spray Residues." He stated, "The FDA has made extensive surveys to determine the toxicity of spray residues on or in foods for human consumption." In 1950, Julius Coon, Director of the Toxicity Laboratory in the Medical School at the University of Chicago, discussed the "Toxicity and Hazards of the Newer Insecticides."

Both safety in application and in storage have often been discussed. Results of our cooperative efforts with the Illinois Department of Public Health (IDPH) were reported in 1964. In 1960, the IDPH reported five deaths caused by insecticide poisoning, two by rodenticides, one by a herbicide, two by venomous stings, and four by lightning. From 1960 to 1962 there were only six deaths caused by insecticides.

The foreword for the Spray School has always stated that the program is "open to all persons interested in the proper, timely, and wise use of agricultural chemicals." Educating users about how to handle chemicals wisely has always been an objective.

Pesticide Residue Problems. In 1951, C.J. Weinman stated, "The problem of insecticide residues is important from the standpoint both of insecticidal efficiency and of hazards to the health of human beings and farm animals." In the same year, G.C. Decker prefaced his remarks on pesticide residues by saying, "Each and every person in any way involved in the use of pesticides to control insects, plant diseases, rodents, or weeds shares with all others likewise involved in the responsibility for making sure that the public health is not endangered." In 1964, F.W. Slife presented the topic "Soil Residue Problems With Herbicides." At the 1965 Spray School, which was dedicated to G.C. Decker and J.H. Bigger, these gentlemen reported on "The Accumulation and Dissipation of Residues Resulting from the Use of Aldrin on Soils."

A review of Spray School programs reveals that topics regarding pesticide residue have appeared regularly. Residue studies were initiated in 1945, and residues still remain our biggest public problem.

Effects of Pesticides on Fish and Wildlife. As early as 1949, the side effects of pesticide usage were concerns. George Bennett with the Illinois Natural

History Survey discussed, "The Effects of Agricultural Chemicals on Aquatic Life," and Willet Wandell, also with the Survey, discussed the "Effects of Agricultural Chemicals on Wildlife." At that time no one envisioned how widespread the use of pesticides would become. Had pesticides not provided such astounding results, use would have been limited and their side effects would still be largely unknown.

Pesticide Resistance. In 1950, W.O. Scott mentioned that, "There are different strains of Canada thistle that respond differently to 2,4-D." In 1950, H.H. Gunderson cited fly-resistance to DDT as one of the reasons for control failures in 1948. In 1951, C.H. Kearns stated, "The acquisition of resistance to certain insecticides or groups of insecticides has pointed to both similarities and differences in the mode of action of various compounds, previously unsuspected." George Weekman from Nebraska reported in 1962 that a few scattered instances of rootworm control failures in 1959 were due to rootworm resistance to insecticides, but "a large number--in the early part of 1960--indicated a serious problem."

No denying, pest resistance to pesticides was a problem then and continues to be a major concern. Note Rick Weinzierl's topic, "Insecticide Resistance: Current Status and Future Challenges."

Insect Treatment Thresholds. In 1950, J.H. Bigger, referring to European corn borers, recommended, "All fields developing 100 egg masses per 100 plants should be examined about a week later. Where single treatments are to be made in fields that still show 50 fresh egg masses per 100 plants, treat 4 to 5 days later." In 1955, Bigger stated, "On field corn, a single treatment should be applied 10 to 14 days after the first hatch provided the plants are 7 to 10 days before tassel emergence and there are 50 or more egg masses per 100 plants." D.E. Kuhlman stated in 1970, "We believe an average of 3 or more rootworm beetles per plant could lead to a serious situation the following year." Today, William Ruesink will discuss "How Complex Should An Economic Threshold Be?" Thresholds require many detailed studies, not only on numbers of insects, but also on the weather and crop. Forty years ago we were well aware that we needed to know a threshold population to determine when to apply insecticides, but we did not have a large enough staff to do the extensive and intensive research required to develop these thresholds. Now economic thresholds are the basis for many pest management programs.

Insecticides as Supplements to Insect Control. In 1950, H.H. Gunderson, reporting on fly and mosquito control in urban areas, warned, "Make sure there is ...a good educational program and that better sanitation practices are being carried out." J.H. Bigger pointed out that insecticides were only a supplementary measure to good control of European corn borers. By 1953 Petty was recommending, "If fly breeding is excessive, do not attempt the fly-control job unless the farmer agrees to clean up the breeding spots." In 1955, R.O. Hall, a commercial applicator, said about fly control on dairy farms, "Sanitation is the first step. Without this, it is impossible to get good results."

Pesticides are intended for use only when other measures fail to prevent or control pest problems.

Insect Diseases. In 1957, John Briggs told about the initiation of field experiments in which pathogens carried on granules were applied to control European corn borers. Naturally-occurring insect diseases have been studied for decades, but the successful introduction and spread of insect pathogens has been slow. *Bacillus thuringiensis (B. t.)* is an early success. Now with the advent of the applied insect pathologist, it has become a vibrant feature of research.

Spray Equipment and Drift. In 1949, B.J. Butler (the first speaker) and Richard Ayres, both agricultural engineers, discussed sprayers and nozzles; in 1950, George Pickard, another agricultural engineer, discussed "Agricultural Drift Studies." These were just forerunners of the extensive studies that have been conducted and reported since.

Other Sources of Income. One objective of the Spray School has been to "extend the season." Proper seeding and fertilizer applications have always been essential topics on the program.

The Sprayer's Bible. Many dealers and applicators once referred to the Spray School Bulletin (now the Illinois Pest Control Handbook) as their "Sprayer's Bible." Copies were well worn before the end of summer. In 1949, the first bulletin was 33 pages long, and in 1985, when the information was still included in one book, it was 581 pages long. In 1986, the book was divided into two distinct publications, but the content has remained complete.

The "Spray School Bulletin" has been one of the most important features of these schools.

A Look Back and Ahead. As we review the past, we realize the enormity of the field of pest control. As shown, the topics have remained the same, but the content and detail have greatly intensified.

For the past 40 years, the Spray School has been our attempt to serve you and to keep you abreast of current events in the field of agricultural pest control. We both serve the same people. Your customer is also our client, and by working together we can better serve him or her. This has been the primary objective of all Spray Schools.

The future is exciting and challenging. The need will be there. The subjects will change, but demand will continue. It has been an honor and privilege to work with you and your predecessors for these 40 years. Here's to your success in the next 40 years.

Effect of Lorsban on Plant Growth, Stalk Rot, and Yield of Corn Hybrids

W. Pedersen, T. Melton, and H. Kirby

INTRODUCTION

There are two primary methods of controlling rootworms in corn. The first method is through crop rotation, which generally involves corn following soybeans on alternate years. The second method is through the use of insecticides applied at planting, which is recommended when corn is planted in fields that were previously corn (no rotation).

It has been observed in several studies that the application of Lorsban to corn following soybeans also showed a yield increase. This yield increase was not attributed to reductions in insect feeding or reductions in nematode populations. It also was observed that the application of Lorsban reduced the amount of lodging; however, stalk rot pathogens were present.

The objectives of this study were to determine if the application of Lorsban to three corn hybrids affected:

1) plant emergence
2) total leaf
3) presence of four stalk rot pathogens
4) yield (bushels per acre)
5) stalk lodging
6) nematode populations

MATERIALS AND METHODS

Field plots. This study was arranged as a split-plot using a randomized complete block design with four replications. The whole plots were insecticide treatments (Lorsban/no Lorsban) and the subplots were five pathogen treatments. Individual plots were four-rows wide (30-inch row spacing) and 45 feet long. Plots were planted on May 5, 1986, and May 1, 1987, with a John Deere Maxi-Merge planter. The population was approximately 24,000 plants per acre.

Pathogen inoculations. Four stalk rotting pathogens (*Gibberella zeae, Macrophomenia phaseoli, Diplodia maydis,* and *Colletotrichum graminicola*) were grown on a mixture of sterilized oat grains and nutrient broth for approximately four weeks. The grain was air dried for 48 hours prior to planting. The oat grains, infested with the pathogens, were applied with the seed at planting. Approximately 25 milliliters of inoculum was applied to each 45-foot row.

Plant growth parameters. Plant emergence counts were made five weeks after planting. Seedling weights also were obtained at that time by removing three seedlings from each plot (from the outer two rows), washing the seedlings, and weighing the seedlings. Leaf areas were obtained by selecting five plants from each plot (outer two rows), removing the leaves, and determining their area using a leaf area meter. This was done at three dates throughout the 1986 season. At two dates in 1987, grain yields were obtained by harvesting the center two rows of each plot, adjusting the grain moisture to 15.5 percent and expressing the weight in bushels per acre.

Disease assessment. Estimates of stalk rot were obtained by spliting seven random plants per plot and rating the first and second internodes above the ground for discoloration. This was done approximately five weeks after pollination. The rating was from 0 to 5, with 0 = healthy and 5 = dead. Lodging estimates were obtained by visually rating the percentage of plants not standing erect at harvest.

Data analysis. All data were analyzed using the appropriate analysis of variance for a split-block design. Comparisons of means was done using a least significant difference (LSD) (P = 0.05) and was done only when the F test from the ANOVA was significant.

RESULTS

All of the parameters measured were significantly affected by the corn hybrids tested and by the Lorsban treatment. None of the parameters were affected by the pathogen treatment. Seedling emergence and root weight of A632 x A619 plants were higher from Lorsban treated plots in 1986 and 1987, respectively (Table 1). Leaf area was significantly higher for the Lorsban treatment for A632 x A619 and B73 x MS71 in 1986, and for all three corn hybrids in 1987 at the final rating date. Grain yields from Lorsban treated plots were significantly higher for A632 x A619 in both years with a 12 percent increase in 1986, and an 11 percent increase in 1987 (Table 2). In 1986, B73 x MS71 also had significantly higher yields from the Lorsban treatment, but not in 1987. Conversely, stalk lodging was lower in the Lorsban treated plots for A632 x A619 and B73 x MS71 in 1986 (Table 3). In 1987, no stalk lodging occurred prior to harvest. Finally, lesion nematode populations were not affected by hybrid, pathogen treatment, or Lorsban in 1986 (Table 4).

SUMMARY

When Lorsban is applied (T-band) to corn following soybeans, increased root development, increased leaf area, increased yield, and reduced stalk lodging were observed for one or two of the three hybrids tested. Laboratory experiments show that Lorsban is fungicidal against several soil-borne pathogens; however, further experiments are needed to determine how Lorsban is affecting plant growth.

Table 1. A Summary of Plant Emergence and Growth Parameters for Three Corn Hybrids Treated with or without Lorsban in 1986 and 1987

Parameter	B73 x Mo17 Lorsban	B73 x Mo17 No Lorsban	A632 x A619 Lorsban	A632 x A619 No Lorsban	B73 x MS71 Lorsban	B73 x MS71 No Lorsban
1986						
Emergence (%)	84	78	87*	79*	89	86
Wet root wt (gms--3 wks)	1.8	1.8	2.4	2.1	1.9	1.9
Leaf area (cm^2) (6/4/86)	427	436	472*	418	421	420
Leaf area (cm^2) (7/8/86)	4481	4351	4288	3883	4877*	4326
Leaf area (cm^2)	4843	5174	5626*	4884	5582*	5252
1987						
Emergence (%)	89	88	91	91	89	90
Wet root wt (gms--3 wks)	2.0	1.9	2.8*	1.9	1.7	1.6
Leaf area (cm^2) (6/22/87)	3160	2988	2941*	2718	3024	2860
Leaf area (cm^2) (7/14/87)	5581*	5294	5332*	5119	5470*	5250

*Significant increase in plant emergence or growth parameter at the 5 percent level.

Table 2. Yield from the Lorsban Study in 1986 and 1987

Hybrid	1986 Lorsban	1986 No Lorsban	1987 Lorsban	1987 No Lorsban
	---------bushels per acre---------			
A632 x A619	126*	113	143*	129
B73 x Mo17	150*	145	172	166
B73 x MS71	160	145	191	187

*Significant increase in yield at 5 percent level.

Table 3. Stalk Lodging Ratings[a] from 1986 and 1987

Hybrid	1986 Lorsban	1986 No Lorsban	1987 Lorsban	1987 No Lorsban
A632 x A619	3.3*	4.0	1.0	1.0
B73 x Mo17	3.6	3.3	1.0	1.0
B73 x MS71	1.8*	2.9	1.0	1.0

[a]Lodging ratings are from 1 = erect with no lodging to 5 = all plants lodged.
*Significant decrease in stalk lodging at the 5 percent level.

Table 4. A Summary of Lesion Nematode Populations in 1986

Hybrid	Pathogen Treatment	Lorsban	No Lorsban
		--number per 100 cc soil--	
A632 x A619	*Gibberella zeae*	37.2	65.0
	Control	50.0	48.0
B73 x MS71	*Gibberella zeae*	39.2	52.0
	Control	39.8	52.0
B73 x Mo17	*Gibberella zeae*	47.3	34.0
	Control	38.0	70.5
	Mean	41.7	43.2[a]

[a]Nematode populations (number per 100 cc soil) are not significantly different at the 5 percent level.

How Complex Should an Economic Threshold Be?

B. Ruesink, K. Steffey, and D. Onstad

"Economic threshold" is usually defined as the pest population density at which control measures should be applied to prevent the pest from reaching damaging levels. In practice, a threshold may be stated as a number of insects per unit sampled or as a level of plant damage with the added condition that the pest must be present. Examples of economic thresholds drawn from Extension Entomology recommendations in Illinois include: an average of 0.5 egg mass per plant (second generation European corn borer on field corn), 6 or more armyworms per linear foot of row (armyworm in small grains), and 50 percent or more of the plants with fresh whorl-feeding damage and live borers present (first generation European corn borer on field corn).

Wise management involves getting the most return for your money, without taking unacceptable risks. This definitely applies to the use of economic thresholds. Deciding whether to use a simple or complex threshold should be based upon economics. Each of the previously stated examples requires information about pest population density, and that information is not free. Growers must either hire someone to collect the information or take the time to collect it themselves. Growers could save sampling costs by using a simpler economic threshold, such as "treat if pests are present." This would greatly simplify the information-gathering process, but these types of thresholds do not provide acceptable economic information.

The additional cost of estimating pest density is justified only when benefits also increase. Two kinds of benefits are expected: (1) unnecessary treatments are prevented; and, (2) treatments will be applied in a more timely fashion to control the target pest. Determining whether a more complicated threshold is worth using is a problem that can be solved through research. Our work has shown conclusively that in most cases it pays to estimate insect densities, especially for major pests of field crops. The growth of businesses offering crop scouting services confirms that growers also believe it pays.

There are situations, perhaps many situations, where information in addition to estimates of pest density should enter into the control decision. In alfalfa, for example, it makes no sense to apply an insecticide for alfalfa weevil control when it's almost time to harvest. Furthermore, 20 small weevil larvae per square foot feeding on plants 18 inches tall would not cause appreciable damage, whereas, 20 large larvae feeding on plants 3 inches tall would be devastating. For these and other reasons, entomologists at the University of Illinois published Circular 1136 (Wedberg et al. 1977), which describes a decision-making scheme that takes into account insect density, crop height, and degree-day accumulations.

Many factors can modify an economic threshold, including the cost of the pesticide and the cost of application, the value of the crop (expected yield and price per unit), abundance of natural enemies, presence of other stress factors (for example, drought, other pests), crop height, crop growth stage, and degree-day accumulation. Economic thresholds that vary with conditions that change during the growing season are often called "dynamic thresholds." Using a dynamic threshold always requires that more data must be gathered before making a decision, and it may also involve extensive computing or other data processing before a decision can be reached. Again, one must decide whether the anticipated improvement in results justifies the extra cost.

To address this point, we present five distinct levels of economic thresholds (Table 1). Two of the levels (4 and 5) are even more complex than those previously discussed. These involve consideration of multiple pests (Level 4) and the use of the full power of comprehensive crop simulation models (Level 5). Most insect pests are presently managed by using Level 2 thresholds, although thresholds for some insects are still at Level 1 and a few are at Level 3. Without doubt the current trend is toward more complex thresholds.

Poston et al. (1983) coined the term "nominal threshold" to define those thresholds based more on expert opinion than on sound scientific data. When data are unavailable or inadequate, we are faced with the choice of using either a nominal threshold or no threshold at all. Extension entomologists in Illinois generally believe that a nominal threshold is the better choice in these situations. Because it is difficult to obtain reliable data about pest-host plant interactions, relatively few legitimate economic thresholds exist among the 100 or so found in the *1988 Illinois Pest Control Handbook.*

Besides the alfalfa weevil threshold already mentioned, the best known (most used) dynamic thresholds have been developed for insect pests of soybeans. Defoliation studies conducted several years ago proved that soybeans are very tolerant of defoliation at most stages of growth, with the greatest potential for yield loss due to defoliation occurring at the time of bloom and early pod fill. Thus, Illinois recommendations suggest treatment for soybean defoliators "when defoliation reaches 30 percent before bloom and 20 percent between bloom and pod fill." Thresholds for bean leaf beetles and green cloverworms include a minimum number of insects per foot of row.

Two other examples of dynamic thresholds already recommended in Illinois (*1988 Illinois Pest Control Handbook*) are for potato leafhopper in alfalfa and for European corn borer in field corn. Insecticide application for leafhoppers is suggested only when leafhopper catch per sweep of a net exceeds one of four density levels, ranging from 0.2 per sweep for alfalfa shorter than 3 inches to 1.5 per sweep for alfalfa taller than 12 inches. For corn borers, a calculation table can be used to allow for changes in borer density (larvae for first generation, egg masses for second generation), crop maturity, expected yield, price per bushel, cost of control, and anticipated effectiveness of the insecticides.

Other dynamic thresholds have been developed in other states but have not yet been promoted in Illinois. Three Level 3 thresholds that might apply to conditions in Illinois have been developed for potato leafhoppers on alfalfa, green cloverworms on soybeans, and corn rootworms on field corn. Level 4 and Level 5 thresholds will probably require use of a personal computer to enter data and arrive at a decision. Perhaps expert systems will prove to be the most effective delivery method.

For potato leafhoppers, Onstad et al. (1984) determined that the economic threshold increased as alfalfa grew taller. They also found that the threshold was higher during years when the average temperatures were cooler than in years when the growing season was warmer. Their management plan offers five options: no treatment, postarrival treatment, postharvest treatment, both postarrival and postharvest treatments, or early harvest with postharvest treatment. However, their plan is of uncertain value for Illinois because it was computed for New York conditions and has not been evaluated here.

Indiana entomologists recommend a decision table for green cloverworm control in soybeans that allows for changes in population density, price per bushel, cost of treating, and stage of development of the plant (Edwards and Bergman 1986). This differs from the current Illinois recommendations by ignoring percentage defoliation but considering economics. For corn rootworms, Indiana entomologists recommend a system that takes into account not only beetle counts, but also behavioral differences between the two species (northern and western), number of plants per acre, and whether the beetle counts were taken in first-year corn or continuous corn (Bergman and Edwards 1987). Both of these dynamic thresholds would likely work equally well in Illinois due to the similarities in agriculture and climate of the two states.

Although many people suspect that the simultaneous presence of several pests puts more stress on a plant than does a single pest, very little research has been done to quantify these multiple effects. Until that is accomplished, we cannot develop Level 4 thresholds. Some research scientists believe that the only way to address multiple pests realistically is through the development and use of detailed computer simulation models for the host crop. Research is progressing on such models, but it will probably be ten years or more before thresholds based on these analyses will be available.

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Table 1. Five Levels of Complexity for Economic Thresholds

Level	Key features
1	Pest presence or absence observed
2	Pest density, or pest presence plus injury level determined
3	Pest density and one or more other factors considered concurrently
4	Multiple pests considered concurrently
5	Comprehensive crop and pest models evaluate the consequences of all possible options

Maximizing Herbicide Performance While Minimizing Costs

F. Baldwin

Please Note: This text is written for Arkansas conditions and weed problems and should not be interpreted as being applicable to all Illinois conditions. The information presented here is only to illustrate some general principles and ideas.

When soybean prices were $7/bu, it was reasonable to spend $20/A or more for herbicides. While weeds still must be controlled, soybean prices of $5/bu or below demand weed control programs with herbicide costs in the $15/A or even the $10/A range. A minimum input weed control program is defined here as a program that will reduce weed populations to below-threshold levels while reducing weed management inputs to the absolute minimum.

FIRST REQUIREMENT: KNOW WEEDS AND THEIR COMPETITIVE ABILITY

Threshold infestation is defined as the level of weed infestation that reduces soybean yields, and, therefore, potential gross returns, more than or the same as the cost of control. Weeds vary in their competitive ability. For example, cocklebur is much more competitive than prickly sida (teaweed). Weed thresholds for selected weeds competing under Arkansas conditions are shown in the following table:

Weed Thresholds for Selected Weeds Competing Under Arkansas Conditions

Weed	Treatment threshold (plants per 20 row ft)
Cocklebur	1
Sicklepod	2
Entireleaf morningglory	2
Pigweed	2
Velvetleaf	4
Prickly sida	20
Annual grass	200

The threshold concept simply means knowing how many weeds it takes to reduce yields. If a weed infestation reaches threshold level or has a history of reaching that level, the weeds must be controlled. This concept also implies that all fields will not be weed-free at the end of the growing season. However, with the exception of weeds where seed production must be prevented, scattered weeds going to seed in a crop will add only a small amount of additional seed to the abundant supply already buried in the soil.

Accurately determining the weed infestation level is necessary to permit the selection of the most economical herbicides. For example, as listed in the following table, per acre herbicide costs to control cocklebur and/or morningglory can range from less than $5/A to over $20/A with little difference in effectiveness.

Cocklebur and Morningglory Control

Herbicide	Approximate cost per sprayed acre: broadcast	Approximate cost per sprayed acre: 1/2 band
	------dollars per acre-----	
Classic 0.5 oz	10	5
Basagran + Blazer		
7 days 1/2 + 1/2 pt	6	3
Basagran + Blazer		
10 days 1 + 1 pt	12	6
Basagran + Blazer		
14 days 1 1/2 + 2 pt	21	10.50
Scepter + Blazer		
14 days 1/3 + 1 pt	12	6

Because the choice of treatment must be precisely fitted to the weed species present, the effectivness of available herbicides on individual weed species must be determined from Extension publications or weed control computer programs where available.

Once the weed problem is determined to be at treatment level, several factors can reduce the cost of control.

BAND APPLICATION

The cost of preemergence and postemergence herbicides can be reduced by one-half to two-thirds by band application in row soybeans. All pre- and post-treatments presented in the following text are for band application unless otherwise noted. Of course, preplant incorporated treatments will be applied broadcast in most cases and will be presented as such.

SPRAY EARLY--REDUCE RATES

Early application of postemergence herbicides has two advantages: (1) better control, and the establishment of height differences between soybeans and weeds; and, (2) reduced rates may be used. Basagran and Blazer or Tackle at rates of 1/2 pt + 1/2 pt/A broadcast or 1/4 pt + 1/4 pt/A banded at the first true leaf (V_1) stage of soybean growth have provided control equal to labeled rates applied later. In University of Arkansas research and test demonstration work, programs using these rates, when repeated at the V_2 stage or followed later by a directed application of 2,4-DB, have consistently provided better weed control than a full rate applied at the V_2 stage of soybean growth. Rates of Scepter and Classic applied postemergence are more dependent upon species rather than timing. Rates of these herbicides can be reduced, for example, when cocklebur is the target weed. The suggested timing for Scepter and Classic, however, is the V_2 stage. Weed control programs using postemergence herbicides in addition to soil-applied herbicides require reduced rates and band application to stay in the $10 to $15 range.

DIRECTED SPRAYS

Postemergence directed sprays of herbicides such as 2,4-DB for cocklebur and morningglory control and Paraquat for red rice control represent two of the most economical herbicide treatments available. An application of 2,4-DB to 8-inch soybeans is an excellent follow-up to a reduced rate of Basagran and/or Blazer-Tackle applied at the V_1 stage or reduced rates of Scepter or Classic applied at the V_2 stage. The herbicide cost is less than $1/A and may be combined with cultivation to reduce the application cost.

SPRAY VOLUME

Research and test demonstration work done over several years shows spray volume seldom influences weed control efficacy. Spray volumes of 5, 10, and 20 gallons per acre (gpa) have performed equally well with preemergence and early post-emergence herbicides. Reduced volumes can increase problems with nozzle stoppage and drift. To maximize efficiency, spray volumes should be at the minimum that is practical in a given operation.

NEW HERBICIDES

Several new herbicides received label clearance in both 1986 and 1987. Scepter and Canopy provided excellent weed control in many instances in 1986. However, due to harsh extremes in weather conditions, more crop injury and more erratic weed control was experienced in some cases than had been expected. While it is believed these new herbicides have tremendous potential, they were entered into the 1987 weed control recommendations on a "trial use" basis until it is certain all the factors responsible for the 1986 problems are known. This suggests they be tried at different rates (where practical) and methods of application (ppi, pre, post) in comparison with standard programs currently in use. The performance of the new herbicides in 1987 was excellent, but carryover problems occurred with Scepter where cotton followed soybeans.

Scepter applied ppi or pre, either tank-mixed or following a grass herbicide, has the potential to control most weeds except hemp sesbania, woolly croton, and hop-hornbeam copperleaf. Others, such as sicklepod and balloonvine, will require a vigorous postemergence treatment in addition to the ppi or pre treatment. Scepter provides fair to good control of entireleaf and ivyleaf morningglories when incorporated with a DNA (Prowl, Treflan, trifluralin). It also provides outstanding control of cocklebur when applied postemergence at reduced rates. Scepter will be recommended alone and in a tank-mix with Blazer or Tackle for control of certain weeds. Where increased control of velvetleaf, prickly sida, or spurred anoda is desired, a reduced rate of Command will be recommended with Scepter ppi.

Canopy is a package mix of Lexone and Classic. It controls the Lexone spectrum of weeds but with added activity on cocklebur and entireleaf and ivyleaf morning-glories. It will be recommended for trial use with a DNA ppi, following a DNA or tank-mixed with Dual or Lasso pre. When applied at seven to fourteen days after emergence, Classic has provided excellent postemergence control of cocklebur, pigweed, hemp sesbania, northern jointvetch, and pitted morningglory. It often provides good control of entireleaf and ivyleaf morningglories and sicklepod, but it is erratic on these species. Following is a capsule summary of the new recommendations that were presented at the 1987 grower meetings. At this writing, the 1988 recommendations had not been determined.

Scepter

- Generally performed well in 1986
- Severe injury occurred on poorly-drained soils under prolonged wet conditions
- Some late season breakthrough of weeds
- DNA plus 1/3 pt Scepter could be a practical alternative to the labeled rate of Scepter

Canopy

- Generally performed well in 1986
- Good control of Lexone weed spectrum + cocklebur and morningglory
- Severe injury occurred on poorly-drained soils under prolonged wet conditions

Classic

- Good but erratic control of sicklepod, entireleaf and ivyleaf morningglory
- Tank mixing with other herbicides may reduce activity

Command

- In Arkansas, recommended at 1 pt 4E/A mixed with Scepter to increase annual grass, velvetleaf, prickly sida, and spurred anoda activity
- Not recommended alone due to weakness on cocklebur, entireleaf and ivyleaf morningglory, and pigweed

EXAMPLE PROGRAMS--COMPONENT PARTS

A. Preplant and preemergence program ($5/A range):

1. 1 to 2 pt/A Treflan or Prowl broadcast
2. 0.75 to 1 pt/A Dual band or 1 qt Lasso banded

B. Postemergence program ($5/A range) ($V_1$ is the first true leaf soybean stage):

1. 0.5 pt Basagran broadcast at V_1 followed by 2,4-DB directed
2. 0.5 pt Blazer or Tackle broadcast at V_1 followed by 2,4-DB directed
3. 0.25 pt Basagran + 0.25 pt Blazer band at V_1 followed by 2,4-DB directed
4. 0.25 oz Classic band followed by 2,4-DB
5. 0.33 pt Scepter at V_2 for cocklebur and pigweed only
6. 0.16 pt Scepter + .5 pt Blazer/Tackle banded (V_2)

C. Postemergence programs that can fit in $10/A range are:

1. 1 pt Basagran broadcast at 10 to 14 days
2. 1 pt Blazer or Tackle broadcast at 10 to 14 days
3. 1/2 pt + 1/2 pt broadcast V_1 or band V_2
4. 0.5 oz Classic
5. 0.16 pt/A Scepter + 0.5 pt Blazer/Tackle banded

D. **Combination programs**

$10/A Program:

1. 1.5 pt Prowl or Treflan
   0.5 pt Basagran or Blazer/Tackle or 0.25 pt each, banded
   2,4-DB directed

2. 1.5 pt Prowl or Treflan or 1 pt Dual Banded
   0.25 oz Classic band V_2
   2,4-DB directed

3. Prowl or Treflan ppi
   0.16 pt Scepter + 0.5 pt Blazer banded

4. Dual or Lasso + 0.33 pt Scepter banded

$15/A Program:

1. Prowl or Treflan ppi
   0.5 pt Basagran + 0.5 pt Blazer/Tackle V_1
   2,4-DB directed

2. Prowl or Treflan + 0.67 pt Scepter/A ppi

3. Prowl or Treflan ppi
   Canopy banded

4. Prowl or Treflan ppi or Dual-Lasso band
   Sencor-Lexone band
   0.16 to 0.33 pt Scepter or 0.25 oz Classic band

5. Prowl or Treflan + 1/3 pt Scepter ppi
   $5 postemergence treatments for escapes

It should be noted that these minimum input programs will not fit all fields. For example, fields with red rice will require broadcast applications of Dual or Lasso. This will likely place them in a $20/A program. Fields with johnsongrass or sicklepod will also require higher cost programs. However, on a large percentage of the Arkansas soybean acreage, weed control programs in the $10 to $15/A range are possible. This must be accomplished through correct species identification, careful choice of herbicides, timely postemergence applications at reduced rates, band applications, economical directed sprays, and judicious use of new herbicide technology.

Designing Herbicide Combinations

M. McGlamery and J. Cantwell

The eight steps in an integrated weed management program are as follows: identify, quantify, qualify, specify, codify, rectify, verify, and modify. It is "ify" "if I" don't follow the steps.

Identify: Do you know your weed problems? Will last year's weeds be this year's weeds? Postemergence herbicides allow exact determination of the target weed seedlings. *Vegetative Identification of Common Row Crop Weeds* is available from the Vocational Agriculture Service for $4.50.

Quantify: Which of these weeds are the worst competitors and which are present in quantities sufficient to cause yield losses?

Qualify: Why do you have certain weed problems? Certain weeds occur on poorly-drained soils. Other weeds are associated with certain tillage practices. What can be done to reduce these problems?

Specify: What herbicides will best control the different species? A table of herbicides and their relative control of different weed species is given in Table 1. This information can help you choose the best herbicide program for a given situation.

Codify: Can you put together a program of practices and herbicides to control your weed problems? What is the most practical and economical program to control the target species?

Rectify: Can I make my weed control program work? If you don't work the plan, there was no need to plan the work. Application and incorporation timeliness are important for soil-applied herbicides. Weed size and environmental conditions greatly affect most postemergence herbicides.

Verify: Did the control program work? Escaped weeds can be controlled by cultivation or postemergence herbicides. Scout the field within two weeks after treatment to verify the control.

Modify: What needs to be changed to make the control program more effective and economical? Look back to look ahead.

Grass and broadleaf herbicides are often combined in premixes or tank mixes to broaden the weed control spectrum. Bicep, Lasso/atrazine, Prozine, Rhino, and Sutazine are formulated premixes for corn. Conquest or Extrazine could be considered as a grass and broadleaf herbicide. Commence, Partner, Salute, Squadron, and Turbo are soybean premixes. Many tank mixes contain the same active ingredients as these formulated mixes.

Two broadleaf herbicides can also be combined to control more weeds. Buctril/atrazine, Laddok, and Marksman are corn premixes that broaden the broadleaf control spectrum. Lorox Plus, Preview, Rescue, and Storm are soybean premixes containing two broadleaf herbicides. Banvel plus 2,4-D for corn and Basagran plus Blazer for soybeans are tank-mixes of two broadleaf herbicides.

A combination of a knockdown and a residual herbicide are often used in minimum- or zero-tillage programs. Bronco and Prelude are premixes of this type. Roundup or Gramoxone is often the knockdown herbicide in zero-tillage tank-mixes. They are usually combined with grass and broadleaf preemergence herbicides.

Sequential or split applications are herbicide combinations applied over time. Many early preplant programs require a split application of an early preplant herbicide plus a preemergence application of the same herbicide. Sequential (overlay) combinations are split in time but involve different herbicides. Basagran, Blazer, Classic, Cobra, and Tackle control broadleaf weeds in soybeans. They are usually sequenced after a preplant or preemergence or before a postemergence grass herbicide. Banvel or 2,4-D are often applied postemergence to control broadleaf weeds in corn sequential to a soil-applied grass herbicide.

In summary, the following questions should be answered when designing herbicide combinations:

1. Do I know my target species?

2. Do I know which weeds are the most competitive?

3. Do I know why I have certain weed species?

4. Do I know which herbicides control which weed species?

5. Can I formulate an efficient and economical program?

6. Can I make my weed control program work?

7. Will I check to see if the control program worked?

Table 1. Relative Weed Susceptibility to Soybean Herbicides

A. Grass Herbicides:

Treflan or Prowl (trifluralin or pendimethalin):
foxtail > panicum > pigweed > shattercane > johnsongrass seedlings

Lasso or Dual (alachlor or metolachlor):
foxtail > panicum > pigweed > yellow nutsedge > nightshade

Command (clomazone):
velvetleaf > foxtail > smartweed = common ragweed > jimsonweed > cocklebur > nightshade > giant ragweed > pigweed

(continued)

Table 1 (continued).

Poast (sethoxydim):
giant foxtail > panicum > barnyardgrass > volunteer corn > shattercane > volunteer cereals

Fusilade (fluazifop):
volunteer corn > shattercane > volunteer cereals > giant foxtail > panicum > barnyardgrass

B. Broadleaf Herbicides--Soil-Applied:

Scepter (imazaquin):
pigweed > smartweed = ragweed > cocklebur > nightshade > jimsonweed > giant ragweed > velvetleaf > morningglory

Pursuit (imazethapyr):
pigweed > velvetleaf > smartweed = ragweed > cocklebur > jimsonweed > giant ragweed > morningglory

Sencor or Lexone (metribuzin):
pigweed > smartweed > velvetleaf > ragweed > jimsonweed >> cocklebur > giant ragweed > morningglory = nightshade

Preview (metribuzin plus chlorimuron):
pigweed > smartweed > ragweed > velvetleaf = cocklebur > jimsonweed > giant ragweed > morningglory > nightshade

Lorox or Linex (linuron):
pigweed = smartweed > ragweed > nightshade > jimsonweed > velvetleaf > cocklebur > giant ragweed > morningglory

Lorox Plus (linuron plus chlorimuron):
pigweed = smartweed = ragweed > nightshade > cocklebur > jimsonweed > velvetleaf > giant ragweed > morningglory

C. Broadleaf Herbicides--Postemergence:

Basagran (bentazon):
smartweed > jimsonweed > cocklebur > velvetleaf > giant ragweed > ragweed > lambsquarters > morningglory > nightshade > pigweed

Blazer/Tackle or Reflex (acifluorfen or lactofen):
jimsonweed = pigweed > smartweed > ragweed > morningglory = nightshade > giant ragweed > cocklebur > velvetleaf

Cobra (fomesafen):
pigweed > ragweed = nightshade > jimsonweed > cocklebur > morningglory > giant ragweed > velvetleaf > smartweed

Classic (chlorimuron):
smartweed > cocklebur > jimsonweed > pigweed > smartweed > ragweed > velvetleaf > giant ragweed > morningglory

Scepter (imazaquin):
pigweed > cocklebur >> morningglory >> jimsonweed >> velvetleaf

Pursuit (imazethapyr):
pigweed > cocklebur > jimsonweed >> velvetleaf > morningglory

1988 Distribution of the Soybean Cyst Nematode in Illinois: Results of an Aerial Survey

T. Melton and E. Sikora

The soybean cyst nematode (SCN), *Heterodera glycines*, was first discovered in Pulaski County in 1959. Since that time, the distribution has increased to include almost all major soybean producing counties in the state. The number of counties confirmed as being infested has increased from 69 in 1984 to 85 in 1988. Yield losses caused by SCN range from three to seven percent depending on the growing season. Despite the rapid increase in SCN distribution, most growers in counties where SCN has not yet been discovered do not consider it as a possible problem, even when symptoms are obvious. Once SCN is discovered in a county, other infestations are often found by additional farmers in other fields in that county. This trend occurs because of an increased awareness of SCN, which is due to the identification of that county as being infested. Therefore, recording statewide distribution of SCN is important to growers and agribusiness in order for early identification--an important management tactic--to be made.

During July of 1987, an aerial survey for SCN was initiated to help identify infested counties that had not yet been reported. All counties shown in Figure 1 as being uninfested in 1987 were surveyed. The survey was done 1,000 feet above ground level in four mile-wide strips. The crew consisted of a pilot, a county Extension adviser or his/her designate to map potential SCN infestations, and two staff members from the University of Illinois Department of Plant Pathology to identify potential infestations. All areas identified from the air as potentially infested areas were sampled by the county Extension adviser and processed by the University of Illinois Plant Clinic. Funding for the aircraft and pilot was provided by the Illinois Soybean Program Operating Board and National Agricultural Pest Information System (NAPIS).

As a direct result of this survey, DuPage, Henderson, Kane, Marshall, and Whiteside counties were found to be infested with SCN (Figure 1). Multiple infestations were found in some counties. Lee and Grundy counties were identified as infested as a result of samples submitted to the Plant Clinic, resulting in a total of seven counties being added to the list of infested counties. Grundy County has since been found to have multiple infestations.

Without exception, at least two counties have been added to the list of infested counties every year since 1980. Seven counties is the most to be added since the last aerial survey conducted in the late 1970s. Although an aerial survey can detect only the most obvious SCN damage, and many infested fields undoubtedly are not identified, it is a very efficient method to help determine the distribution of SCN.

No fields in Illinois are immune to becoming infested with SCN. All soybean growers would be wise to scout their fields for SCN about five to six weeks after planting. Digging roots in several places in a field to look for the lemon-shaped cysts is all the work that is involved. Early identification of SCN, before it causes noticeable damage, is a key to economical management.

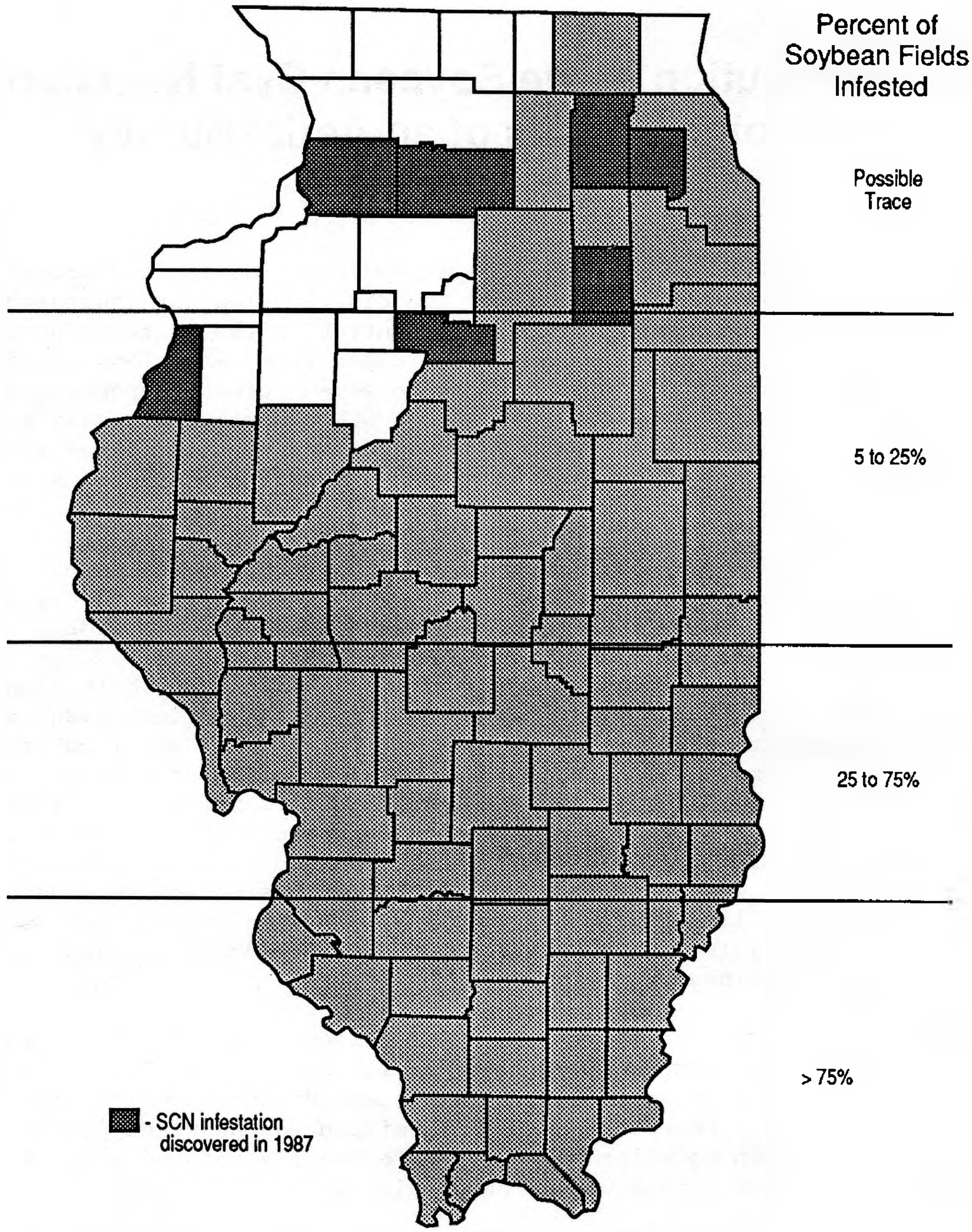

Figure 1. Illinois counties with known infestations of the soybean cyst nematode as of November 1, 1987.

Herbicides As Potential Hatching Factors for the Soybean Cyst Nematode

G. Noel, R. Kraus, and D. Edwards

Hatch and emergence of cyst nematode juveniles are influenced by physical and chemical factors. Chemical stimulation or inhibition has been reported for natural agents such as root difusates and aqueous extracts from nematodes, and for artificial substances including inorganic ions, salts, and various organic compounds. Hatching is also affected by temperature and water potential.

Several pesticides, including nematicides, fungicides, and herbicides, have been evaluated in vitro for their stimulation or inhibition of nematode hatch. Increases in cyst nematode populations in the field following herbicide treatment were associated with herbicide effects on egg hatch.

During research at the University of Illinois, we found that the herbicides vernolate, metribuzin, alachlor and trifluralin, evaluated at 1.25, 2.5, 5.0, and 10.0 ppm of the formulated material, stimulated hatch and emergence of soybean cyst nematode (*Heterodera glycines*) juveniles when compared to tap water controls. Metolachlor had no effect. Figure 1 shows that vernolate and metribuzin were more effective than alachlor and trifluralin during the first seven days. During the next seven days vernolate and metribuzin activity declined, alachlor activity remained the same, and trifluralin activity increased. During the third week there was no stimulation of hatch after placing cysts in water.

Field experiments in southern and central Illinois demonstrate that interactions between certain herbicides and the nematicide aldicarb can occur. Using recommended rates for the chemicals, soybean yield was increased in Franklin County when vernolate, trifluralin, metribuzin, and the combination of trifluralin + metribuzin were used with aldicarb. Alachlor did not interact with aldicarb. Although not as striking, similar results were obtained in Vermillion County.

The preliminary results presented in this paper indicate that certain herbicides can affect soybean cyst nematode hatch and that herbicides can interact with aldicarb to affect soybean yield. Much additional work needs to be done before we can understand what environmental factors influence pesticide interactions and soybean cyst nematode. The new herbicides that are now being marketed should be evaluated to determine whether they affect hatch under laboratory conditions and nematode population dynamics and soybean yield on the farm.

Table 1. Effect of Aldicarb and Herbicides on Yield of 'Williams 79' Soybean

	Franklin Co.		Vermillion Co.	
Treatment	- Aldicarb	+ Aldicarb	- Aldicarb	+ Aldicarb
	-----------------bushels per acre-----------------			
Vernolate	36.2	43.5*	32.9	35.5*
Alachlor	39.1	42.0	35.6	36.4
Trifluralin (T)	38.6	45.1*	34.4	37.0*
Metribuzin (M)	38.1	44.9*	35.6	37.4
T + M	37.6	44.2*	35.4	36.4
Control	40.8	42.8	34.2	33.8
CV%	6.2		4.8	
	$FLSD_{.05}$ for any two treatment means = 5.5		$FLSD_{.05}$ for any two treatment means = 2.2	

*Indicates significant difference between aldicarb treatments within the herbicide.

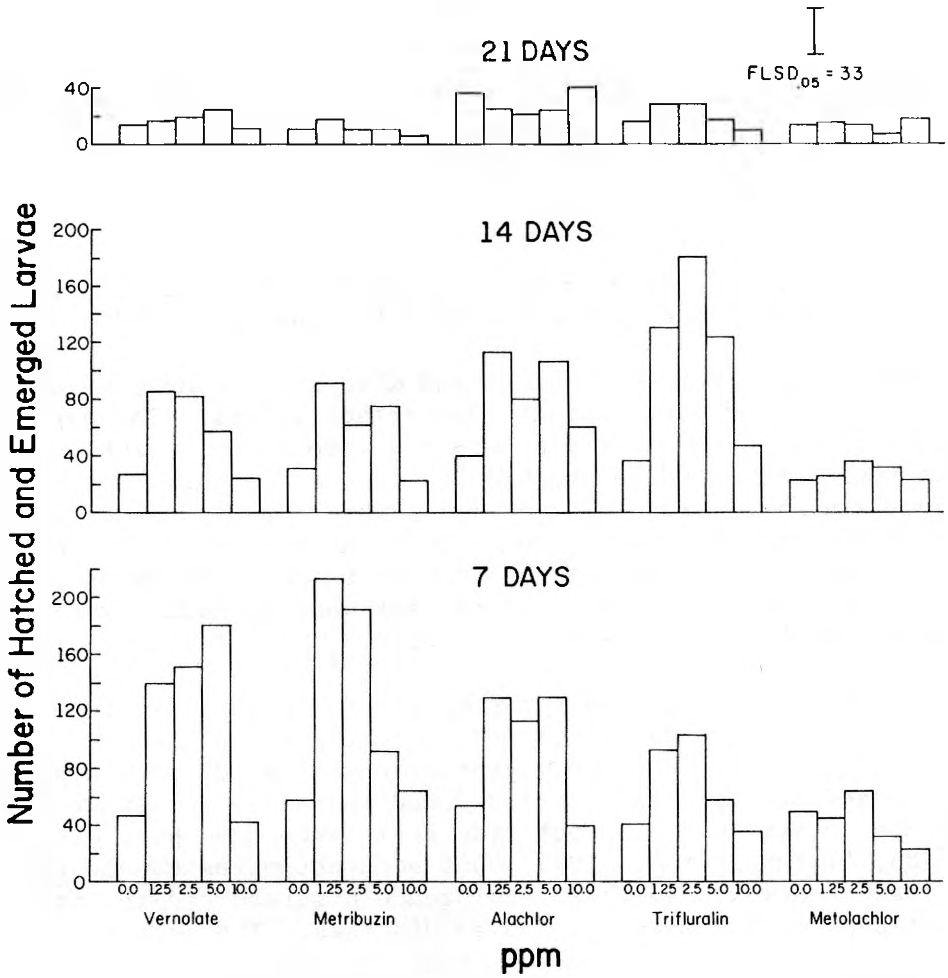

Figure 1. Number of hatched and emerged H. glycines *juveniles after treatment with the herbicides vernolate, metribuzin, alachlor, trifluralin, and metolachlor at concentrations of 0.0, 1.25, 5.0, and 10.0 ppm for 7 and 14 days followed by 7 days in tap water. FLSD is for any two treatment means.*

Insecticide Resistance: Current Status and Future Challenges

R. Weinzierl

The topic of insecticide resistance can best be introduced by reporting just a few of the recent observations presented by G.P. Georghiou (1986):

> Populations of more than 447 insect and mite species have developed resistance to one or more insecticides or acaricides. The magnitude of resistance can be most clearly understood when cross-resistance, multiple resistance, and geographically separate occurrences of resistance are considered. For example, when separate species x insecticide resistance combinations are counted, the total exceeds 1,600. In 1984, 59 percent of the species in which resistance had been documented were pests of crops, 38 percent were of medical/veterinary importance, and 3 percent were beneficials.

The impact of insecticide resistance can be great. Results include pest control failures, increased control costs related to multiple applications, and/or the use of new, more expensive compounds, greater negative environmental impacts of increased rates and multiple applications, and increased losses to resistant pests. Monetary losses due to insecticide resistance have been estimated (Georghiou 1986; Pimental et al. 1979), but such estimates cannot take into account the loss of human life where resistance has resulted in the failure of control programs aimed at vectors of human diseases. The impact of resistance on anopheline mosquito control programs designed to prevent the transmission of malaria exemplifies the sometimes tragic results of insecticide resistance (World Health Organization 1976).

In addition to the direct costs of insecticide resistance, indirect impacts include a negative influence on future insecticide development. The identification, synthesis, and eventual marketing of a new insecticide involve phenomenal investments, and the chances to recoup those investments and make a profit are greatly reduced if the market life of the insecticide is likely to be limited (even in only a few major crops) by the development of resistance.

Solutions to resistance problems will not be easy to design or carry out. Managing resistance now and in the future must involve reducing the selection pressure placed on pest species; effective approaches also may involve specifically planned sequences or combinations of selection pressures. Improvements in resistance management will depend on dramatic increases in research addressing the genetics, biochemistry, and population dynamics of resistance. Extensive changes in pesticide policies and marketing may be necessary. Solutions may involve the use of new compounds that differ markedly in structure and mode of action from current pesticides, but resistance will not be managed successfully by simply relying on the continued development of new compounds to replace those lost to resistance.

This paper presents a broad review of insecticide resistance. It includes discussion of resistance mechanisms, cross-resistance, and the scope of insecticide resistance problems, especially in the midwestern United States. It contains not only a summary of pertinent knowledge, but also a summary of unanswered questions and research needs. It includes some controversial proposals regarding the future management of insecticide resistance. Note that this is not a presentation of original research, but a condensation of published findings and proposals. The "experts" and the leaders in the field of insecticide resistance are the authors whose publications are cited in this review, and they are the individuals to be credited for the information presented herein. Two excellent publications that serve as references for most of the issues addressed in this review are those edited by Georghiou and Saito (1983) and by Glass (1986a).

THE NATURE OF INSECT RESISTANCE TO INSECTICIDES

Resistance and Tolerance

To understand and to manage pest resistance to pesticides, it is essential to differentiate between two related conditions, species-wide tolerance and population resistance. When used in describing insect responses to pesticides, these terms carry slightly different meanings than they do when used in discussing host plant resistance to pathogens or insects. A population of insects described as resistant and a different species described as tolerant may both survive exposure to similar levels of a certain insecticide. Examining the response of a single insect or a single group of test insects does not reveal the difference between these two conditions. To differentiate between tolerance and resistance requires knowledge of the insecticide's toxicity to several representative populations of the insect species and some means to estimate change in toxicity over time.

Although individuals within a species exhibit differences in response to a certain insecticide, the term tolerance is usually used to describe species-wide ability to survive a given level of pesticide exposure. That level may be identified rather arbitrarily, and different researchers might disagree about what constitutes "tolerance," but the key in this concept is that the level of susceptibility is (despite some variation) species-wide. It does not involve reduced susceptibility in selected populations, and it is not the result of a change in susceptibility in response to exposure to the pesticide. Humans exhibit a relative tolerance in their response to antibiotic drugs, as doses that kill bacterial pathogens do not injure or kill treated persons. Humans did not develop or evolve an ability to survive antibiotic exposure; differences in antibiotic toxicity in humans and bacteria simply reflect differences in biochemical processes in the two organisms. Insects exhibit similar differences in susceptibility to highly selective insecticides. Beetles, for instance, are not killed by exposure to relatively high concentrations of available commercial formulations of *Bacillus thuringiensis kurstaki*, a bacterial insecticide effective only against Lepidopterous larvae, or Pirimor (pirimicarb), a selective aphicide. Less obvious levels of tolerance exist for many broad-spectrum insecticides. Most aphid species survive applications of carbaryl, even though those applications are very effective against Chrysomelid beetles such as the corn rootworm adults. These examples of tolerance involve no selection-induced shift in susceptibility over time and no major differences among separate populations of the same species.

In contrast to tolerance, resistance is characterized by differences among populations of the same species and by change in susceptibility resulting from pesticide exposure. As a manufacturer initially develops an insecticide, an economical and environmentally acceptable application rate may kill all individuals in the target pest population during laboratory and small-scale field tests. However, differences in susceptibility exist within the species. Individuals that are substantially less susceptible are present, even if only at very low frequencies, in at least some wild populations. In the presence of the pesticide, only these individuals survive and reproduce. Because the mechanisms that allowed their survival were genetically determined, a high percentage of their offspring (possibly the only offspring produced in the treated area) also are able to withstand insecticide exposure. If intense use of the insecticide continues on future pest generations, selection for increased ability to survive insecticide exposure results in the evolution of resistance in this pest population. Populations of the same species in different locations may not be exposed to such intensive use of the same insecticide and may remain very susceptible.

This distinction between resistance and tolerance is not always evident in publications on insecticide resistance (for example, Chio et al. 1978). It might in fact be argued that tolerance, as I have explained it here, is the result of natural selection pressures that over countless generations have resulted in the evolution of the biochemical processes that enable the tolerant species to survive exposure to a specific toxicant. Although such a process may not differ significantly from the development of resistance within a population, it is important in the understanding of resistance and the development of resistance management programs that the short-term response of populations to pesticide application be distinguished from species differences that have evolved over centuries.

Resistance Mechanisms

Insect resistance to insecticides results from mechanisms that involve altered behavioral patterns, reduced cuticular penetration, increased insecticide metabolism, and/or reduced sensitivity at the target site. Separate types of resistance mechanisms may occur individually or in combination in a given insect population.

Behavioral resistance, as characterized by Lockwood et al. (1984), results from "those actions, evolved in response to the selective pressures exerted by a toxicant, that enhance the ability of a population to avoid the lethal effects of that toxicant." Lockwood et al. (1984) further recognized that behavioral resistance may be stimulus-dependent or stimulus-independent. Where resistance is stimulus-dependent, insects in the resistant population detect a toxic substance before encountering a lethal dose and then avoid the toxicant. Where stimulus-independent resistance occurs, the insect exhibits behavior that results in occupation of habitats characteristically not contaminated by the toxic substance. At least some degree of behavioral resistance in insects has been detected or demonstrated in populations of many species, including red flour beetle and granary weevil (Pinnegar 1975; Prickett and Ratcliffe 1977), German cockroach (Rust and Reierson 1977, 1978), fall armyworm (Young and McMillan 1979), and horn fly (Lockwood et al. 1985).

Brief discussion of behavioral resistance in the horn fly exemplifies this resistance mechanism. Flies exhibiting behavioral resistance more frequently feed at the bellies of cattle if the animals are treated with ear tags containing a pyrethroid insecticide; they avoid animals' backs and shoulders where "normal" horn flies characteristically feed. This behavioral mechanism prevents exposure to the greatest concentrations of insecticide rubbed from ear tags onto the animals' shoulders. (Horn fly resistance also appears to involve target site insensitivity--a discussion follows.) A more detailed review of behavioral resistance was presented by Georghiou (1972).

Reduced cuticular penetration is another resistance mechanism that contributes to the survival of insects exposed to insecticides. The effectiveness of many insecticides applied to crops, soil, or building surfaces relies upon penetration of the insecticide through target insects' cuticles and into their circulatory systems. Where insecticide penetration is somehow slowed, internal detoxication processes stand a better chance of keeping pace with pesticide intake. Studies have detected reduced penetration in resistant populations of the house fly (Forgash et al. 1962; Plapp and Hoyer 1968; Georghiou 1971; Sawicki 1970), the mosquitoes *Aedes aegypti* and *Culex fatigans* (Matsumura and Brown 1963; Shrivastava et al. 1970), and the tobacco budworm, *Heliothis virescens* (Vinson and Brazzel 1966; Vinson and Law 1971). The gene responsible for reduced penetration of dieldrin in house flies also results in reduced penetration of several other insecticides (Plapp and Hoyer 1968); mechanisms that retard penetration in other species also are thought to act against several different insecticides.

Reduced penetration alone seldom results in high levels of resistance; instead, slowed penetration is most important when combined with additional resistance mechanisms, especially those which speed insecticide metabolism (Plapp and Hoyer 1968; Georghiou 1971; Plapp 1986). This relationship makes sense, as reduced rates of penetration would slow the pace at which improved metabolic systems would have to degrade the insecticide to avoid toxic effects. Reduced penetration provides the greatest benefit in resistance to readily metabolized insecticides such as malathion in contrast to more stable compounds such as dieldrin (Benezet and Forgash 1972; Matsumura and Brown 1963). For additional review of reduced cuticular penetration as a mechanism of resistance, see Matsumura (1983) and Georghiou (1972).

Most studies of insecticide resistance have addressed metabolic resistance. It is helpful to realize that metabolic processes in all organisms work to detoxify harmful foreign compounds. Wilkinson (1983) points out that the presence of detoxication enzymes in insects represents the net effect of centuries of insect evolution in the presence of naturally occurring toxic compounds. In detoxifying insecticides, cellular processes transform toxic lipophilic (fat soluble) compounds into less toxic, hydrophilic (water soluble) products that can be excreted. The primary steps in detoxication include reactions catalyzed by enzymes such as mixed function oxidases (mfo's), hydrolases, glutathione-S-transferases, and esterases. The primary reactions produce more reactive compounds that can be conjugated (in secondary reactions) with amino acids, sugars, phosphates, etc.

Production of detoxication enzymes represents an energy expenditure for any organism. In the absence of toxicants, too great an investment in detoxication systems wastes energy that could be devoted to growth and reproduction. Therefore, evolution in an environment that contains only moderate amounts of toxic substances would favor those individuals with adequate, but not overly developed detoxication mechanisms. This explains why a species does not display widespread tolerance to a new type of insecticide as it is first introduced. However, as populations are pressured by insecticides, individuals possessing genes that direct the greatest detoxication activity are most likely to survive and reproduce. The result of continued selection by insecticides is a resistant population characterized by enhanced detoxication systems. Terriere (1982), Wilkinson (1983), Dauterman (1983), and Yasutomi (1983) have summarized pathways of insecticide metabolism and the role of metabolism in insecticide resistance.

A phenomenon related to metabolic resistance involves the induction of detoxication enzymes, a process reviewed by Terriere (1983, 1984). In induction, certain compounds trigger increased production of detoxication enzymes. Among known inducers are certain chlorinated hydrocarbon insecticides, the substituted urea diflubenzuron, phenobarbital, and certain secondary plant compounds; insects in which induction has been observed include the house fly, black blow fly, American cockroach, variegated cutworm, alfalfa looper, and black cutworm (Terriere 1983). Understanding the genetic basis of induction lies in accurately describing the roles of structural and regulatory genes that control the production of detoxication enzymes. Although the role of induction in insecticide resistance remains unclear, the idea that elevated detoxication capabilities might be maintained in a ready state, but not fueled until needed, represents a clear evolutionary advantage.

"Target site insensitivity" has for many years served as a final, sometimes unclear explanation for insecticide resistance. Where insects are exposed to a usually fatal dose of an insecticide, the compound penetrates the integument, and metabolism fails to detoxify the poison, it is logical to assume that mortality will occur. If the insect is not killed, the "target site" at which disruption of processes normally occurs must be "insensitive" to the toxicant. Early evidence of target site insensitivity was provided by studies in which high DDT concentrations were observed in resistant strains of the house fly (Sternburg et al. 1950; Babers and Pratt 1953).

To discuss target site resistance, a brief review of the action of major groups of insecticides is required. Chlorinated hydrocarbons and pyrethroids are thought to act by: (1) blocking nerve sodium channels and disrupting normal sodium-potassium balance in polarization and depolarization of the nerve during impulse transmission; and/or (2) interfering with the nerve enzyme calcium-ATPase. Narahashi (1983) proposed mechanisms in which disruption of sodium channels by chlorinated hydrocarbons or pyrethroids might be averted in resistant populations. Early discoveries of resistance in house flies were attributed to a *kdr* factor; in the house fly, horn fly, and several mosquito species, *kdr*-resistance to chlorinated hydrocarbons and pyrethroids appears to result from target-site insensitivity (Miller et al. 1983). In cockroaches resistant to DDT, nerve calcium-ATPase, normally very sensitive to DDT, is not inhibited by high concentrations of this insecticide (Matsumura 1983). Organophosphates and carbamates bind with and inhibit the action of acetylcholinesterase, an enzyme responsible for restoring the readiness of a synapse once a nerve impulse has been transmitted. Altered acetylcholinesterase, which differs in its sensitivity to specific organophophates and carbamates, has been reported to occur in resistant populations of the southern cattle tick, the green rice leafhopper, the house fly, the mosquito *Anopheles albimanus*, and the two-spotted spider mite and other species in the same genus (Hama 1983).

Cross-Resistance and Multiple-Resistance

Georghiou (1972) defined cross-resistance as those cases in which a single resistance mechanism confers resistance against various toxicants; he defined multiple-resistance as those cases in which an insect's resistance to various toxicants is conferred by different coexisting mechanisms. An understanding of the resistance mechanisms outlined previously makes cross-resistance a logical occurrence. For example, since DDT and pyrethroids are thought to act in the same way at the same target site, it should not be surprising that *kdr*-regulated resistance to DDT should offer resistance to pyrethroids as well (as demonstrated by Omer et al. 1980; Priester and Georghiou 1980; and Malcolm 1983). Similar action of mfo's, hydrolases, glutathione-S-transferases, and esterases against more than one insecticide explain cross-resistance within the organophosphates and the carbamates. Cross-resistance is one reason why new insecticides that are closely related to current compounds may not be effective against resistant pests.

Although multiple-resistance sometimes includes aspects that are not well-understood (see Georghiou 1972), it is important to note that no known resistance mechanisms preclude the development of additional resistance mechanisms (Georghiou 1986). In 17 pest species including the Colorado potato beetle, house fly, tobacco budworm, diamondback moth, green peach aphid, and two *Anopheles* mosquito species, multiple-resistance has evolved to the point that individual populations display resistance to five classes of insecticides (DDT, cyclodienes, organophosphates, carbamates, and pyrethroids) (Georghiou 1986).

INSECTICIDE RESISTANCE AND THE MANAGEMENT OF INSECT PESTS IN MIDWESTERN AGRICULTURE

Midwestern farmers have experienced few serious problems resulting from insecticide resistance. The best known and most documented incidence of resistance in this area involves the corn rootworms. Ball and Weekman (1962, 1963) and Bigger (1963) originally described resistance to cyclodienes (aldrin and heptachlor), and follow-up studies indicated the increase and later decline in the frequency and intensity of this resistance (Hamilton 1965; Sechriest 1967; Ball 1977). The cyclodienes were used in decreasing amounts through the mid-1970s when further use was prevented by EPA regulations. By the mid-1960s, however, the shift to organophosphate and carbamate insecticides had begun, and compounds in these classes are still used for rootworm control. Although there have been some control problems and some indications of shifts in adult susceptibility to certain products, no dramatic episodes of resistance have occurred since the shift from the cyclodienes (Ball 1973, 1977; Chio et al. 1978). It is important to realize, however, that not every control failure has been investigated, and that many studies addressing rootworm resistance have bioassayed adult beetles, not larvae. Terriere (1982) discussed the fact that larval and adult stages of several insects respond differentially to insecticide exposure; therefore, results of adult bioassays should not be interpreted as accurate indicators of larval susceptibility in all instances. Our understanding of rootworm resistance, though more thorough than our knowledge of resistance in many other pests, is not as complete as it might seem.

Few other resistance problems have developed in Midwest agricultural pests. Malathion-resistant Indianmeal moth populations have been detected throughout the Midwest, including Illinois (Beeman et al. 1982). Although populations of red flour beetle resistant to malathion have been reported from several areas of the United States (Haliscak and Beeman 1983), the status of malathion resistance in this pest in Illinois is not known. Champ and Dyte (1976) reported numerous additional cases of resistance in stored product insects from around the world, but similar levels of resistance have not developed in populations of stored-grain insects in the Midwest.

Horn fly resistance to pyrethroid insecticides has been documented in Illinois (Weinzierl et al. 1987) and surrounding states. Pyrethroid resistance in house flies has been detected in the United States (Meyer et al. 1987); but although house fly resistance to the pyrethroids is suspected in Illinois, it has not been clearly documented. House fly resistance to a range of other insecticides is well-known (Georghiou 1986).

Additionally, management recommendations for mites in apples take into account occurrences of resistance in pest and beneficial mite species documented by Glass (1960), Croft and Meyer (1973), and Strickler and Croft (1981). Although they are not pests of agricultural systems, fleas, cockroaches, and mosquitoes (some of which are important livestock pests) are insects in which resistant populations have been detected in many regions.

The impact of resistance in the north central states should not be underestimated by judging this problem solely by the number of occurrences in this region. Instead, some indirect costs also must be assessed. The development of insecticides intended for foliar application to crops is largely dependent on prospects for the use of those insecticides on cotton. Where current resistance problems in cotton signal too great a chance for cross-resistance and a candidate insecticide is shelved, resistance has an inconspicuous, but very real impact on Midwestern corn and soybean pest management.

RESISTANCE MANAGEMENT

Factors That Influence Resistance Development

The management of insecticide resistance requires an understanding of the conditions that favor resistance development. Georghiou (1983) outlined the factors that influence selection of resistance in field populations of insects; a modified version of his outline is presented in Table 1. Although all of the factors outlined in Table 1 are important in resistance development, only a few will be discussed in this paper.

Genetic and biological attributes of a pest in the field are factors over which managers can exert little or no control (although Leeper et al. (1986) point out many innovative ways in which we might make major advances in this area). Nonetheless, understanding the role of genetic and biological factors helps in estimating "resistance risk" for given pest-pesticide combinations and in designing methods to manage resistance.

Among the genetic factors that influence resistance development, "fitness" is a topic that warrants brief discussion here. Resistance management plans (or hopes) often include the assumption that resistance will decline rapidly in the absence of pesticide pressure. Although this assumption often is true, the rapid decline of resistance depends upon resistant forms being less "fit" than susceptible individuals if pesticide selection is not applied. General fitness would be described by survival rates, mating competitiveness, and reproductive performance. However, resistant forms are not always at a competitive disadvantage (Beeman and Nanis 1986), and fitness differentials are not always great enough that decline in resistance occurs quickly enough to help in designing pest management plans (Roush and Plapp 1982; Curtis et al. 1978).

Reproductive rate is another biological factor that influences resistance development. Comparatively high numbers of generations per year or offspring per generation obviously mean that many individuals will be exposed to insecticide selection pressure in a given time period. This results in an increased likelihood that the population will include individuals with the necessary genetic composition to confer resistance. As a result, if all other conditions were standardized, pests that produce many individuals and many generations per year (such as flies and mosquitoes) would be more likely to develop resistance in a given time period than those that produce fewer offspring and only one or two generations per year (as do many agricultural pests in the north central states). Similarly, within a species, resistance is likely to develop first in populations inhabiting warmer climates where greater numbers of generations are produced each year.

Behavioral factors that are characteristic of a species influence exposure of individuals within that species to insecticides. If individuals of a species are found in a diversity of habitats within an area, it is likely that insecticide-susceptible individuals will be present even after intense application of an insecticide to a given crop in that area. Similarly, if a species feeds on several crops (polyphagy), it is likely that some insecticide-susceptible forms will be present even after intensive use of an insecticide on one of the host crops. Conversely, it is less likely that large numbers of susceptible individuals will survive intense insecticide application to their host crop if the species is monophagous (feeds on only one crop). Resistance development is affected differently in these situations because where susceptible individuals survive, their mating with resistant insects can serve to dilute resistance and maintain susceptibility.

Migration among fields or habitats similarly helps to slow resistance development. As susceptible insects migrate into a treated area after the insecticide has dissipated, they mate with resistant insects that have survived the application. The result again is a "dilution" of resistance genes.

Long-range migration can play a different role by providing a method by which resistance is transported to new areas. Pests that migrate annually into the north central states from southern states provide examples of the potential role of migration in resistance transport. Corn earworm, black cutworm, armyworm, fall armyworm, potato leafhopper, southern corn rootworm, and corn leaf aphid all migrate into Illinois each year. Although resistance is not yet a problem in these pests in Illinois, if resistance develops in southern states where longer seasons may mean more insecticide applications and greater selection pressure, the resulting problems will not be confined to those southern states.

The operational factors identified in Table 1 refer to the ways we use pesticides. Resistance results from the selection pressure exerted by a pesticide; the need for resistance is regulated by the degree to which the insecticide is the main factor that determines which individuals will survive to reproduce. Insecticide persistence generally encourages the evolution of resistance, because the persistent insecticides remove susceptible insects from the population for a longer period. Frequent applications and high rates of application speed resistance development in a similar fashion. The selection of resistance is hastened by the use of insecticides closely related to compounds for which resistance already exists. A factor that is often overlooked in understanding the development of resistance is the insect stage which is the target of control efforts. Although most damage to agricultural commodities is caused by immature stages of insects, adults are sometimes the damaging stage (leaf-feeding beetles and biting flies, for example). When insecticide applications to control adults are made after some individuals have reproduced, the insecticide exerts reduced selection pressure.

Detection and Monitoring of Resistance

Brent (1986) outlined the following objectives for attempts to detect or monitor pesticide resistance: (1) to make an initial estimate of the frequency of occurrence of a basic genetic potential for resistance; (2) to gain an early warning of resistance progression; (3) to determine the success of a resistance management program; (4) to provide an explanation of the cause of control failures; (5) to determine the incidence, geographical distribution, and severity of a documented resistance problem; and, (6) to guide individual field level selection of pesticides. To describe insect or mite responses to pesticides and determine resistance levels has traditionally involved the use of bioassays--the treatment of sample groups of the target insect with a range of insecticide doses or concentrations and the subsequent evaluation of mortality. Treatments usually are made by direct application to the insect (topical treatments or injections) or by treatment of glass, filter paper, or cloth on which the insects are later placed. A variety of additional treatment methods also have been used. Results of these bioassays are summarized by estimating the pesticide dose required to kill 50 or 95 percent of the test population. Terriere (1982) explained the use of bioassays in the study of insecticide toxicology.

Among recent advances in approaches to insecticide bioassays, Miyata (1983) described tests in which carboxylesterase activity (an indicator of metabolic resistance) can be measured in individual insects. Dennehy et al. (1987) described a "practitioner-assessable" bioassay for estimating resistance severity in spider mites. This bioassay was designed to enable producers to make pesticide selection decisions based on the bioassay results.

Perhaps the greatest problems historically and currently in the detection and monitoring of resistance are associated with bioassay design and sample numbers. Brent (1986) and Roush and Miller (1986) have summarized these problems. Roush and Miller (1986) pointed out that LD_{50}'s and LD_{95}'s computed from standard bioassays usually do not differ substantially between resistant and susceptible populations in early stages of resistance development. Because of this, initial resistance development goes undetected despite bioassay efforts. Such a problem is exemplified by the failure of a resistance detection program to indicate a problem with pyrethroid resistance in *Helicoverpa armigera* in Australia until control failures occurred in the field (Gunning et al. 1984).

Roush and Miller (1986) and Dennehy et al. (1987) have proposed the use of a "discriminating dose" rather than a range of pesticide doses to detect resistance development once dose-response relationships are understood in susceptible populations. Although discriminating-dose bioassays improve the likelihood of early resistance detection, to ensure a high probability of detecting resistant forms if they are present still requires testing of at least hundreds of individuals from each population of interest (Roush and Miller 1986). Brent estimated that resistance frequencies of 1 in 1,000 result in obvious reduction in control within two applications or generations where the pesticide provides approximately 90 percent control. To detect resistance at this frequency (later detection offers little or no chance for resistance avoidance) requires examining the response of almost 3,000 individuals (Brent 1986). Where detection or monitoring programs cannot practically utilize such high numbers of insects, they offer little benefit in early detection of resistance, and resistance management programs must be designed without reliance on such tests to provide early warnings (Roush and Miller 1986).

Approaches to Resistance Avoidance and Resistance Management

The simplest recommendations for avoiding the development of resistance to insecticides have been and still are centered around minimizing selection pressure by minimizing pesticide use. In current agricultural systems, that means using resistant crop varieties and appropriate cultural practices to minimize pest numbers and/or pest damage. Where pests occur at damaging levels only occasionally, the use of established sampling and threshold recommendations can reduce the application of insurance treatments where they are unnecessary.

Georghiou (1983) outlined resistance management strategies related to pesticide use; his outline is presented in modified form in Table 2. Under "management by moderation," Georghiou listed several practices that reduce selection pressure on insect populations. The use of low doses and less frequent applications, applications of less persistent compounds, and leaving segments of populations or local areas untreated clearly reduce selection for resistance. Treating only adults (where useful) allows for some reproduction prior to resistance selection and imposes selection on a smaller number of individuals in comparison to treating against immature stages. Note that this listing discourages the use of controlled-release formulations. Pyrethroid resistance in the horn fly developed in response to controlled-release applications in cattle ear tags, yet manufacturers have followed this resistance episode not by abandoning ear tags that provide continuous release of an insecticide, but by incorporating different insecticides in ear tags.

Table 2 includes management strategies described as "management by saturation." These approaches, directed at controlling resistant individuals, involve the use of high doses or synergists.

The use of high doses represents an attempt to kill susceptible insects and those with intermediate levels of resistance (the heterozygotes). Where this can be accomplished, subsequent resistance development proceeds at a reduced pace equivalent to that seen where resistance mechanisms are functionally recessive (Taylor and Georghiou 1979). Such an approach can work if necessary treatment doses are determined (and practical) and high-dose applications are initiated before resistance development has produced even a fairly low percentage of highly resistant insects (homozygous for resistance). Application of high-dose management techniques might be effective in rare instances, but the negative aspects of such approaches--monetary costs, nontarget impacts in the environment, and increased residues on treated commodities--prohibit their use in most situations.

The use of synergists in combination with insecticides is designed to increase the effectiveness of insecticides against resistant insects by blocking the insects' enhanced metabolic detoxication systems. Where the proper synergist is used to interfere with the key detoxication process, this approach can be effective. The use of synergists for resistance management has been limited by costs, human safety concerns (synergists block detoxication processes in humans also), and the phytotoxicity and photo-instability of common synergists. The development of additional resistance mechanisms in target insects can overcome the benefit of synergist-insecticide combinations (Georghiou 1962).

"Management by multiple attack" involves the use of insecticide mixtures or rotations. The usefulness of mixtures assumes that resistance mechanisms are different for each component and that these mechanisms are so rare in the population that they do not occur together in any single individual. In such a situation, individuals that survive one component of the mixture are killed by the other component. To be effective, mixtures must be applied before resistance to either compound has developed significantly. The actual effectiveness of mixtures has differed in separate studies (MacDonald 1983; Lagunes 1980), illustrating that management by the use of mixtures must be based on results of extensive research on the insecticide components and the pest species.

Insecticide rotation employs the use of two or more insecticides in an alternating or cycling order. The success of rotation for resistance management depends upon reduced fitness of resistant strains in the absence of the selecting insecticide. Where resistant strains do not exhibit reduced fitness, rotations will be of no value (as described earlier in the discussion of factors presented in Table 1).

In discussing resistance management, it is important to point out that resistance can develop in beneficial as well as pest species (Croft and Meyer 1973; Strickler and Croft 1981; Hoy 1985). Making use of field- or lab-selected strains of pesticide resistant natural enemies is an approach that can be useful in some crop systems. Hoy (1985) reviewed advances in development of pesticide-resistant predator mites.

Improving Resistance Management for the Future

Effective resistance management is complicated by several factors. The following paragraphs present some of these factors and discuss possible means of overcoming them.

Perhaps the most all-encompassing limitation in our attempts at resistance management is our lack of knowledge about basic aspects of resistance. This knowledge shortfall exists at both the professional scientist and the producer-applicator levels. A recent report of the National Research Council Committee on Pesticide Resistance recognized this problem and included in its recommendations a call for increased research on the biochemistry, physiology, and molecular genetics of resistance mechanisms (Glass 1986b). This group also called for increased Extension educational efforts concerning resistance (Glass 1986c). Croft and Dover (1986) suggested that research centers be established for the study of resistance so that research continuity might not be disrupted by annual changes in research priorities outlined by major funding agencies. They also raised the idea that a resistance tax might be assessed to fund increased research efforts; they estimated that a 2 cents per pound tax would generate over $20 million annually.

An additional problem in resistance management is posed by the limited diversity of current insecticides. Although numerous active ingredients and countless formulations of these ingredients are available, they provide little variation in mode of action. Chlorinated hydrocarbons and pyrethroids attack nerve sodium channels; organophosphates and carbamates inhibit the action of acetylcholinesterase. The National Research Council report recognized the importance of this problem and called for investigation of new target sites and types of pesticides. Hammond and Soderlund (1986) discussed recently discovered and possible new sites for pesticide action.

Resistance management is not enhanced by current incentives for pesticide marketing or agricultural production. Commercial agriculture rewards individual productivity, not areawide cooperation; marketing efforts stress immediate profits. These pressures urge farmers and pesticide marketing professionals to strive for short-term profits, not the maintenance of pest management over many years. To prevent short-term profit making from undermining pesticide resistance management, Dover and Croft (1986) have suggested that pesticides characterized as high-risk for resistance development be limited in sale and use by requiring a prescription from a professional adviser.

CONCLUSIONS

Insecticide resistance is the result of evolutionary processes that result in the increase in a range of mechanisms that enable insects to survive in the presence of toxic compounds. Populations may develop resistance to more than one compound by evolving a single mechanism that confers cross-resistance, or as a result of the evolution of separate, coexisting mechanisms that defend against different toxicants.

Insecticide resistance does not currently represent a crisis-level problem in the Midwest, but resistance has disrupted certain pest management practices in this region. Assessing resistance costs should include consideration of the impact of other regions' resistance episodes on the future development of insecticides.

As we attempt to manage resistance it is evident that for most pests we have accumulated too little baseline data about their pesticide susceptibility. In general, we have too few resources allocated to the detection of resistance at a stage where serious problems can still be averted. Given this situation, ongoing, generic efforts to avoid resistance are essential. Where specific information needed to design an individualized resistance management program is unavailable, sound biological principles indicate that management by moderation is the most appropriate action. Maintaining the usefulness of pesticides may be aided most by adopting a philosophy that pesticides are valuable resources that must be managed with prudence in order to extend their effectiveness.

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Table 1. Factors Influencing the Development of Insecticide Resistance[a]

A. Genetic Factors

1. Frequency, number, and dominance of resistance alleles
2. Penetrance, expressivity, and interactions of resistance alleles
3. Past selection by other chemicals
4. Extent of integration of resistance with "fitness" factors

B. Biological and Ecological Factors

1. Biotic Factors

    a. Generations per year
    b. Offspring per generation
    c. Monogamy/polygamy, parthenogenesis

2. Behavioral and Ecological Factors

    a. Isolation, mobility, migration
    b. Monophagy/polyphagy
    c. Fortuitous survival

C. Operational Factors

1. The Insecticide

    a. Chemical nature of the insecticide
    b. Relationship to earlier-used chemicals
    c. Persistence of residues

2. Application

    a. Application rate, frequency, area of treatment
    b. Life stage(s) selected

[a]Modified from Georghiou (1983).

Table 2. Strategies for Resistance Management[a]

A. Management by Moderation

1. Low rates of application
2. Less frequent applications
3. Chemicals that exhibit short environmental persistence
4. Avoidance of controlled-release (= sustained-release) formulations
5. Select against adults where practical
6. Local instead of areawide applications
7. Leave certain areas or portions of population untreated
8. Preservation of "refugia"
9. Maximize economic threshold to minimize applications

B. Management by Saturation

1. Use high doses to kill intermediate forms (the heterozygotes)
2. Use synergists to suppress detoxication mechanisms

C. Management by Multiple Attack

1. Insecticide mixtures
2. Insecticide rotations

[a]Modified from Georghiou (1983).

Pesticide Regulation: A Step Toward the Future

T. Walker

On August 18, 1987, Governor James Thompson signed House Bill 2380 amending the Illinois Pesticide Act. This amendment is a step toward the future for pesticide regulation in Illinois. It is a far-reaching amendment and assures the safe and proper use of pesticides in this state.

The changes to the Illinois Pesticide Act are as follows:

Section 4. Definitions. "Agricultural Commodity" was amended to include aquatic products as defined in the Aquaculture Development Act.

"Pesticide Dealer" is defined as any person who distributes registered pesticides to the user.

"Business" means any individual, partnership, corporation, or association engaged in a business operation for the purpose of selling or distributing pesticides or providing the service of application of pesticides in this state.

Section 5. Misbranded. The term "misbranded" was amended to include the statement that if the pesticide container is not in compliance with child resistant packaging requirements as set forth by the United States Environmental Protection Agency, the product is deemed to be misbranded.

Section 6. Registration. This Section was amended to clean up some confusion about registration fees. The Section now states that any business registering a pesticide product at any time during one year shall pay the annual business registration fee of $250. Each legal entity of the business shall pay the annual business registration fee. In addition, a $50 fee per product is also required.

Section 9. Licenses Requirements and Certification. This Section contains an important amendment that states that recertification is now required every <u>three (3)</u> years, rather than every five years. All renewal applications must be submitted to the department within <u>60 days</u> following the date of expiration. <u>If a person does not renew within 60 days, he or she must take all certification examinations again.</u>

Section 11. Certified Pesticide Applicators. This Section was amended to require a $10 license fee for private applicators. A private pesticide applicator shall be assessed a fee of $5 for a duplicate license.

Section 13. Pesticide Dealers. This Section was amended to require any dealer who sells restricted-use pesticides to be registered with the Department of Agriculture. Dealers who hold a Structural Pest Control license with the Illinois Department of Public Health or a Commercial Applicator's license with the Illinois Department of Agriculture are exempt from the registration fee but <u>must register with the Department</u>. Commercial-Not-For-Hire applicators are no longer exempted, and if they are also dealers, they must take the examination, register, and pay the $100 license fee.

Section 14. Unlawful Acts. This Section contains three amendments. First, the entire Section was amended to state that all violations cover <u>any person</u>. This means that enforcement action can now be taken against a person who violates the act, even if they are not licensed by the Department.

Section 14 (G) was amended to read, "[If any person] used or supervised the use of a pesticide without qualifying as a certified applicator or licensed operator."

Section 14 (K) was added as a violation and states, "[If any person] purchased pesticides by using another person's license or using or purchasing pesticides outside of a specific category for which that person is licensed or any other misrepresentation."

Section 15. Enforcement. This Section was amended to clarify that the Department has the right to inspect and collect samples in any place where pesticides are produced, manufactured, sold, or distributed.

This Section also states that any person who impedes, obstructs, hinders, or otherwise prevents or attempts to prevent the Director in the performance of official duties shall be guilty of a Class A misdemeanor. Any person using physical force against the Director in the performance of official duties shall be guilty of a Class 4 felony.

Section 24. Section 24 was renamed "Criminal Penalties." It now reads, "Any person violating any provisions of this Act or regulations adopted thereunder shall be guilty of a Class A misdemeanor with a fine of not less than $5,000."

A new Section, 24.1, entitled "Administrative Actions and Penalties," is an innovative and unique approach to pesticide enforcement penalties. It reads as follows:

1. The Director is authorized after an opportunity for an administrative hearing to suspend, revoke, or modify any license, permit, special order, registration, or certification issued under this Act. This action may be taken in addition to or in lieu of monetary penalties assessed as set forth in this Section. When it is in the interest of the people of the State of Illinois, the Director may, upon good and sufficient evidence, suspend the registration, license, or permit until a hearing has been held. In such cases, the Director shall issue an order in writing setting forth the reasons for suspensions. Such order shall be served personally on the person or by registered or certified mail sent to the person's business address as shown in the latest notification to the Department. When such an order has been issued by the Director, the person may request an immediate hearing.

2. The hearing officer upon determination of a violation or violations shall assess one or more of the following penalties:

   A. For any person applying pesticides without a license or misrepresenting certification, a penalty of $500 shall be assessed for the first offense and $1,000 for the second and subsequent offenses.

B. For violations of a stop use order imposed by the Director, the penalty shall be $2,500.

C. For violations of a stop sale order imposed by the Director, the penalty shall be $1,500 for each individual item of the product found in violation of the order.

D. For selling restricted-use pesticides to a noncertified applicator, the penalty shall be $1,000.

E. For violations of the Act and Rules and Regulations, administrative penalties will be based upon the total violation points as determined by the Use and Violation Criteria as set forth in Paragraph 3 of this Section.

When the total violation points are 6 or less, the Department may send an advisory letter to the violator. When the total violation points are 7 to 13, the Department shall issue a warning letter to the violator. The monetary penalties shall be as follows:

Total Violation Points	Monetary Penalties
14-16	$750
17-19	$1,000
20-21	$2,500
22-25	$5,000
26-29	$7,500
30 and above	$10,000

3. The following Use and Violation Criteria establishes the point value which shall be compiled to determine the total violation points and administrative actions or monetary penalties to be imposed as set forth in Paragraph 2(E) of this Section:

A. Point values shall be assessed upon the harm or loss incurred:

1. A point value of 1 shall be assessed for the following:

a. Exposure to a pesticide by plants, animals, or humans with no symptoms or damage noted.
b. Fraudulent sales practices or representation with no apparent monetary losses involved.

2. A point value of 2 shall be assessed for the following:

a. Exposure to a pesticide which resulted in:

1. Plants or property showing signs of damage including but not limited to leaf curl, burning, wilting, spotting, discoloration, or dying.
2. Garden produce or an agricultural crop not being harvested on schedule.
3. Fraudulent sales practices or representations resulting in losses under $500.

3. A point value of 4 shall be assessed for the following:

   a. Exposure to a pesticide resulting in a human experiencing headaches, nausea, eye irritation, and such other symptoms which persisted less than 3 days.
   b. Plant or property damage resulting in a loss below $1,000.
   c. Animals exhibiting symptoms of pesticide poisoning including but not limited to eye or skin irritations or lack of coordination.
   d. Death to less than 5 animals.
   e. Fraudulent sales practices or representations resulting in losses from $500 to $2,000.

4. A point value of 6 shall be assessed for the following:

   a. Exposure to a pesticide resulting in a human experiencing headaches, nausea, eye irritation, and such other symptoms which persisted 3 or more days.
   b. Plant or property damage resulting in a loss of $1,000 or more.
   c. Death to 5 or more animals.
   d. Fraudulent sales practices or representation resulting in losses over $2,000.

B. Point values shall be assessed based upon the signal word on the label of the chemical involved:

Point Value	Signal Word
1	Caution
2	Warning
4	Danger/Poison

C. Point values shall be assessed based upon the degree of responsibility:

Point value	Degree of Responsibility
2	Accidental (such as equipment malfunction)
4	Negligence
10	Knowingly

D. Point values shall be assessed based upon the violator's history for the previous three years:

Point Value	Record
2	Advisory letter
3	Warning letter
5	Previous criminal conviction of this Act or administrative violation resulting in a monetary penalty
7	Certification, license, or registration currently suspended or revoked

E. Point values shall be assessed based upon the violation type:

1. Applicator Oriented:

Point Value	Violation
1	Inadequate records
2	Lack of supervision

Point value (cont.)	Violation (cont.)
2	Faulty equipment
	Use contrary to label directions:
2	a. resulting in exposure to applicator or operator
3	b. resulting in exposure to other persons or the environment
3	c. precautionary statements, sites, rates, restricted-use requirements
3	Water contamination
3	Storage or disposal contrary to label directions
3	Pesticide drift
4	Direct application to a nontarget site
6	Falsification of records
6	Failure to secure a permit or violation of permit or special order

2. Product Oriented:

Point Value	Violation
6	Pesticide not registered
4	Product label claims differ from approved label
4	Product composition (active ingredient differs from that of approved label)
4	Product not colored as required
4	Misbranding as set forth in Sec. 5 of the Act (4 points will be assessed for each count)

3. Any penalty not paid within 60 days of notice from the Department shall be submitted to the Attorney General's Office for collection. Failure to pay a penalty shall also be grounds for suspension or revocation of permits, licenses, and registration.

4. Private applicators, except those private applicators who have been found by the Department to have committed a "use inconsistent with the label" as defined in subsection 40 of Section 4 of this Act, are exempt from the Use and Violation Criteria point values.

As can be seen by these amendments, Illinois has taken a bold step forward in pesticide regulation.

Corn Rootworm Control: Do Root Ratings Tell the Whole Story?

K. Steffey and K. Kinney

Corn rootworms are the most economically important insect pest complex attacking corn in Illinois. Although difficult to measure, the value of the damage caused by these insects has been estimated to be as high as $60 million annually (Turpin et al. 1972). In addition, corn growers spend millions of dollars to prevent corn rootworm larval damage each year. As a consequence, management of corn rootworms usually represents the most costly insect management input for many farmers in Illinois.

Corn rootworms have been and continue to be the subjects of numerous research projects conducted in Illinois. Most of our efforts have been directed toward evaluating control of rootworm larvae with soil insecticides and determining the economic impact of rootworm larval damage. In light of this, we established two objectives when we prepared this manuscript:

(1) To present the results of the corn rootworm insecticide trials we conducted in 1987, and
(2) To discuss the relationship between rootworm larval damage to the corn root system and subsequent yield.

Extension and research entomologists at the University of Illinois and the Illinois Natural History Survey conducted several trials in 1987 to evaluate the level of root protection provided by soil insecticides. However, we will report the results from only four of these trials in this paper. These four trials were established primarily to compare the effectiveness of the currently registered insecticides and several experimental insecticides for control of corn rootworm larvae. The efficacy of both planting-time and cultivation-time applications were investigated. We present the methods, results, and discussion of the results in the first portion of this paper and in the tables.

Because of some interesting observations we made at the Monmouth trial site in 1987, we devote the second portion of this paper to a discussion of the relationship between the root ratings used to evaluate rootworm larval damage and subsequent corn yield. An historical perspective of this relationship as it has been reviewed in entomological literature is provided as background. The methods we used to examine specific details of the Monmouth plot are presented after the historical discussion. However, the analyses of the data collected from the Monmouth trial had not been completed by the time this manuscript was submitted for publication in these proceedings, so the results are not included.

CORN ROOTWORM INSECTICIDE EFFICACY TRIALS--REGISTERED AND EXPERIMENTAL COMPOUNDS

Methods

The effectiveness of soil insecticides for controlling corn rootworm larvae was evaluated in four trials located near Urbana, Bloomington, Monmouth, and DeKalb, Illinois, in 1987. All of the trials were established in fields that had been planted to corn around mid-June in 1986. Trap crops of late-planted corn typically attract numerous egg-laying rootworm beetles late in the summer, so larval infestations the subsequent year are usually heavy.

Corn was planted on May 5, May 6, May 7, and May 14 at Urbana, DeKalb, Monmouth, and Bloomington, respectively, in 30-inch rows with a John Deere 7000 series four-row planter. The Monmouth, Urbana, and Bloomington plots were cultivated on June 4, June 5, and June 8, respectively, with a four-row cultivator pulled behind a tractor. Because the trial near DeKalb was designated strictly as no-till, it was not cultivated.

Each treatment, except where otherwise noted, was applied to a single row approximately 100 feet in length. The experimental design was a randomized complete block with four replications. Five or six nontreated check rows were included within every replication at each site.

Granular insecticides applied at planting and at cultivation were metered through Noble units mounted on each of the planter units and on the cultivator. The planting-time granules were applied in furrow, in a 7-inch band ahead of the firming wheels on the planter, or in a 7-inch band behind the firming wheels. Spring tines mounted behind each planter unit were used to incorporate the insecticides into the soil at planting, except where otherwise noted. Insecticides applied at cultivation were incorporated into the soil with the cultivator shovels.

To continue experiments regarding different insecticide application techniques that we initiated last year, we applied Lorsban 15G beneath the soil surface with a split boot apparatus at Urbana, Monmouth, and Bloomington. Two-thirds of the recommended rate of Lorsban 15G (2/3 rate = 5.35 oz per 1,000 feet of row) was metered evenly into a pair of fertilizer disk openers located in front of and on either side of the seed furrow disk opener. The granules were placed as close as possible to the same depth underground as the seeds were planted. The remaining one-third of the recommended rate of Lorsban 15G (1/3 rate = 2.65 oz per 1,000 feet of row) was applied directly into the seed furrow. The result of this application technique was three discrete insecticide placement sites beneath the soil surface at seed depth. In order to balance the effect of the fertilizer disk openers on the planter as it moved through the soil, split boot applications of Lorsban 15G were made to two adjacent rows within each replication.

Liquid insecticides applied at cultivation time were sprayed at 20 pounds per square inch (psi) in 38 gallons per acre through two flat fan nozzles (Spraying Systems 8002E) mounted on either side of the row to be treated. The sprays were applied in a 15-inch band directed toward the base of the corn plants. The insecticides were incorporated into the soil with the cultivator shovels.

Evaluations

The only results reported in this paper are the root-damage rating data. Five root systems from each treatment in every replication of each trial were dug, washed, and rated for rootworm damage. We used the Iowa State University root-rating scale (Hills and Peters 1971) described as follows:

(1) No damage, or only a few minor feeding scars.
(2) Feeding scars evident, but no roots eaten off to within 1 1/2 inches of the plant.
(3) Several roots eaten off to within 1 1/2 inches of the plant, but never the equivalent of an entire node of roots destroyed.
(4) One node of roots completely destroyed.
(5) Two nodes of roots completely destroyed.
(6) Three or more nodes of roots destroyed.

Other evaluations and information, such as plant population counts, weather data, and field histories are presented in the 1988 edition of *Illinois Insecticide Evaluations: Field and Forage Crops*, a report of all the insecticide efficacy trials we conducted in 1987.

Results and Discussion

The results of our root-rating evaluations are presented in Tables 1 through 4. The discussion is divided into appropriate sections when trends in the data are apparent. Some of these trends were consistent among all locations. Use of the word "significant" in this section refers to statistical significance as defined in the tables.

The level of rootworm larval damage in the nontreated check rows was extremely high (average root ratings greater than 5.0) at all four locations. Because all of these trials were established in areas that had been planted to trap crops in 1986, the heavy larval pressure was not unexpected. Average root ratings in the nontreated check rows represent an index of the density of the larval population in the plot area, that is, the higher the root rating, the larger the larval population.

The trials located near Urbana, Bloomington, and Monmouth received only small amounts of rainfall throughout May and June in 1987. The soil at all three of these locations was quite dry at the time applications of insecticides at cultivation were made. The soil at DeKalb was relatively moist throughout May and June. Weed pressure was fairly light at all locations except DeKalb where a severe infestation of weeds placed the corn plants under considerable stress. Corn plants in this trial were stunted and spindly.

Registered insecticides applied at planting. With few exceptions, the currently registered soil insecticides provided good to very good root protection in all four trials. The average root ratings in the rows treated with registered insecticides were usually below 3.0 (the suggested "economic injury level") and were frequently below 2.0. These results were quite impressive considering the heavy rootworm pressure and environmentally stressful conditions. The only registered products for which the average root ratings were greater than 3.0 were Broot 15GX (3.15) and Thimet 20G (3.8) at DeKalb (Table 2), Aastar at both DeKalb (3.5, Table 2) and Bloomington (3.45, Table 4), and Mocap at Bloomington (3.4, Table 4). The average root ratings for these products in the respective trials were significantly higher than the average root ratings for most of the other registered products, but were significantly lower than the average root ratings in the nontreated checks.

Counter 15G applied in furrow provided an equivalent level of root protection as when it was applied in a 7-inch band. The average root ratings for these two methods of application of Counter were not statistically different in any of the trials in 1987. Counter was also applied at one-half the labeled rate (1/2 rate = 4 oz per 1,000 feet of row) at Urbana and Monmouth (Tables 1 and 3). Although the average root ratings were numerically higher (2.5 at Urbana, 2.7 at Monmouth) than the average root ratings for the labeled rate of Counter (1.95 and 2.1, respectively), they were not statistically different. Entomologists have known for years that the level of root protection provided by soil insecticides is often adequate at three-fourths or even one-half the labeled rate under certain environmental conditions. Unfortunately, environmental conditions are difficult to predict, so the full labeled rates are still recommended.

Tom Baughman, a graduate student in entomology at the University of Illinois, has examined the behavior of terbufos (active ingredient of Counter 15G) in the soil for the past two years. He has compared the activity of terbufos after application of Counter both ahead of and behind the firming wheels of the planter and has found that soil type and texture and environmental conditions affect whether the different placements of Counter provide adequate root protection. To continue this work, we applied Counter 15G both ahead of and behind the firming wheels at Urbana (Table 1). Counter applied behind the firming wheels was not incorporated into the soil. The average root rating for Counter applied behind the firming wheels (3.9) was significantly higher than the average root rating for the conventional application of Counter (1.95). Because the soil remained dry at Urbana throughout May and June when rootworm larvae were feeding, the lack of incorporation by the firming wheels or any other implement probably restricted the distribution of terbufos into the root zone. As a consequence, the level of root protection was not adequate. The results in 1987 were similar to those observed in several other trials conducted since 1985, and they indicate why application of soil insecticides ahead of the planter's firming wheels (or press wheels) is recommended.

A new formulation of ***Dyfonate*** (Dyfonate 20G on montmorillonite clay granules) was evaluated at all locations in 1987, as was the currently marketed Dyfonate 20G. We observed that the montmorillonite clay flowed more consistently and was easier to calibrate than the regular Dyfonate. The average root ratings for the new Dyfonate 20G and regular Dyfonate 20G were not statistically different. In fact, the average root ratings for the new formulation were numerically lower than the average root ratings for regular Dyfonate in three of the four locations.

Dyfonate 20G was also applied in furrow as a comparison for other potentially phytotoxic products and at one-half the labeled rate (1/2 rate = 3 oz per 1,000 feet of row) at Urbana (Table 1). The average root ratings for both of these treatments (2.05 and 2.45, respectively) were not statistically different from the average root rating of the conventional application of Dyfonate 20G (1.90). As expected, however, some phytotoxicity was observed in the rows treated with Dyfonate 20G in furrow. Although the half rate provided adequate root protection in this trial, the application of less-than-labeled rates is not recommended, for reasons mentioned previously.

Furadan 15G provided very good root protection (average root ratings of 2.5 or less) at all locations in 1987. In fact, the average root rating for Furadan 15G at DeKalb (1.55, Table 2) was significantly lower than the average root ratings for all other treatments. Interestingly, Furadan 15G applied at planting at Monmouth (Table 3) provided good root protection (average root rating of 2.15) in

1987 in the same plot location where it has failed to control rootworm larvae in the past. The Monmouth field has had a history of Furadan use, and Furadan applied at planting usually degrades very rapidly at that location, probably due to enhanced microbial degradation. However, soil microbes are not very active under dry soil conditions, so we speculated that the dry soil at Monmouth in May and June prevented rapid breakdown of Furadan. As a consequence, Furadan lasted long enough in the soil to provide adequate root protection.

Lorsban 15G was applied both in a 7-inch band and in furrow at all locations in 1987. In addition, Lorsban 15G was applied with a split boot technique at Urbana, Monmouth, and Bloomington. The average root ratings for all of these treatments were not statistically different at any of the locations, but some numerical differences were observed. The average root rating for Lorsban 15G applied in a 7-inch band (2.2) was lower than the average root ratings for the in-furrow (2.95) and both split boot applications (2.87 and 3.13) at Urbana (Table 1). However, we encountered some problems with application at Urbana where we had tried the split boot technique for the first time. We made some adjustments to the technique before we made the applications at Monmouth and Bloomington, so the application of Lorsban 15G in a split boot was more uniform at these locations. The average root ratings for Lorsban 15G applied in a split boot at Monmouth (2.5 and 2.65, Table 3) and at Bloomington (1.95 and 2.0, Table 4) were lower than the average root ratings for Lorsban 15G applied in a 7-inch band (2.85 and 2.5, respectively). The relative success of the split boot application bears further research. By placing the insecticide beneath the soil surface and closer to the root zone where rootworm larvae feed, the consistency of root protection should be improved.

Registered insecticides applied at cultivation. With the exception of Counter 15G, none of the soil insecticides applied at cultivation provided an acceptable level of root protection. Although the average root ratings for these treatments were usually significantly lower than the average root ratings in the nontreated checks, they were above the so-called economic injury level of 3.0. Rootworm larvae hatched early in 1987, so we believe our cultivation applications may have been made too late to give some of the chemicals enough time to move into the root zone. In addition, the dry soil conditions probably impeded the movement of the insecticides.

The average root ratings for Counter 15G at Monmouth (2.85, Table 3) and Bloomington (3.35, Table 4) were significantly lower than the average root ratings for all other products applied at cultivation. The average root rating for Counter at Urbana (2.65, Table 1) was numerically lower, but the difference was not significant. Counter may have provided adequate root protection where the other insecticides did not because of its inherent volatility.

Experimental soil insecticides. In general, the experimental soil insecticides we evaluated in 1987 provided very good root protection against rootworm larval feeding. Only Stauffer's (now ICI's) SC-0567 failed to keep the average root ratings consistently below 3.0 (Table 1). Nevertheless, the higher rates (6, 9, and 12 oz per 1,000 feet of row) of SC-0567 applied in furrow provided very good root protection.

Several new organophosphates (DuPont's Fortress, Uniroyal's UBI-B8451, Dow's XRD-429, CIBA-Geigy's Brace, and American Cyanamid's AC-301467 and AC-301468) provided very good root protection at the trials in which they were evaluated. Average root ratings for all rates and placements of these products were below

3.0, and several were below 2.0. Lance, a carbamate that has been discontinued by BASF, provided good root protection at DeKalb, Monmouth (a Furadan-history field), and Bloomington. Holdem, an experimental combination of phorate (active ingredient of Thimet) and ethoprop (active ingredient of Mocap) formulated by United Agri-Products, provided very good root protection when applied at both the 6 oz and 12 oz rate at Urbana (Table 1) and Monmouth (Table 3).

Force, ICI's new soil pyrethroid, provided good root protection at all four locations. The average root ratings for both the 8 oz and 10 oz rates were not statistically different from each other and were significantly lower than the average root ratings in the nontreated checks. These 1987 results were consistent with results observed by many entomologists in the Midwest over the past few years. The average root ratings for Force are often numerically higher than those of some of the other treatments, but they are usually below 3.0.

Conclusions

The results from our corn rootworm insecticide evaluation trials in 1987 indicated that when the registered insecticides are calibrated and applied properly and at the labeled rates, they can provide good root protection, even under certain environmentally stressful conditions. We also observed that timing of application and environmental conditions can affect the performance of soil insecticides applied at cultivation.

Several experimental soil insecticides provided very good root protection in 1987, and evaluation of their performance should be continued. Because the split boot application of Lorsban 15G provided promising results, this technique should be evaluated and refined for potential use.

ROOTWORM-DAMAGE RATINGS AND CORN YIELD

The relationship between rootworm damage and subsequent corn yield has been studied by entomologists throughout the Corn Belt since growers began using soil insecticides for rootworm control. It has been a frequently debated topic for nearly four decades, and the relationship is still unclear despite the sizable amount of data that has been accumulated. Root-damage ratings are still open to interpretation and are frequently misused.

Under the current economic conditions, farmers are looking for an economic return on their investments. Consequently, the relationship between rootworm damage and yield is an important concern to anyone spending money for rootworm control. Appropriate questions have been: "How much rootworm larval injury can be tolerated before corn yield is significantly reduced?" and "How do different varieties of corn respond to corn rootworm larval feeding?" The following review of the literature reveals only a few of the many studies initiated to answer these questions.

In the late 1940s and 1950s, several investigators evaluated the effects of using the new synthetic insecticides, including chlorinated hydrocarbons, to control corn rootworm larvae. Hill et al. (1948) reduced rootworm larval populations by 96.4 percent with broadcast applications of gamma-BHC, and by 77.4 percent with an application of gamma-BHC at cultivation. However, they did not find statistically significant yield reductions even though yields of nontreated corn were 15.4 percent and 27.4 percent less than the yields of treated corn in their respective trials.

After these initial studies, several researchers reported various average maximum yield reductions attributable to corn rootworm damage in their trials. Yields from nontreated plots were compared with yields from plots treated with soil insecticides, and the differences in yield were associated with protection provided by the insecticides. Some of the representative studies and respective yield reductions attributed to rootworm damage were published by Muma et al. (1949)--an average of 16.1 percent yield reduction in two trials; Cox and Lilly (1953)--an average of 19.9 percent yield reduction in six trials; Lilly (1954)--an average of 16.1 percent yield reduction in seven trials; Burkhardt (1954)--an average of 37.8 percent yield reduction in two trials; and Apple (1957)--an average of 19.9 percent yield reduction in two trials. It was evident even then that the relationship between rootworm damage and corn yield was not consistent.

In the late 1950s and early 1960s, entomologists and plant breeders were trying to locate potential sources of resistance to rootworm larvae among inbred lines of corn. In addition, they were searching for a reliable method of evaluating rootworm larval damage. Eiben and Peters (1962) examined the corn roots of certain inbred lines and recorded the total number of roots, total number of nodes, the pounds of pressure required to pull a root system from the soil (vertical pull technique), total number and percentage of roots damaged by rootworms, and number of rootworm larvae collected from the roots. However, they did not offer a standard method for evaluating rootworm larval damage.

Apple and Patel (1963) studied the sequence of attack by northern corn rootworm larvae on the roots of corn. They observed very little damage on the first two whorls of roots (the first roots to develop), only slight damage on the third whorl of roots, and severe damage on the fourth, fifth, and sixth whorls of roots. They speculated that the small roots of the first two whorls probably provided very little support for the plant but performed very efficiently in obtaining nutrients and water during July when the other whorls of roots were severely damaged. They used the yield data from their trial (81.2 bushels per acre for nontreated corn, 83.5 bushels per acre for insecticide-treated corn) to support their statement. They also found that nondamaged meristematic tissue continued the elongation of the main roots and the proliferation of lateral roots, such that rootworm damage that occurred early in the season could be obscured by root regrowth.

Peters (1963) posed one of the most significant questions of the time when he asked how entomologists were to determine the influence of rootworms on corn, or vice versa. He listed several techniques for evaluating corn rootworm damage, among which he included counting rootworm forms, determining the percentage of roots fed upon, assigning visual ratings (although these were not explained), measuring the volume of root systems, and determining percentage lodging and yield loss. He mentioned that visual ratings were fast, but only as good as the observer is consistent. He also stated that measuring yield differences were among the most remote criteria for measuring insect-plant relationships, but that yield differences have been extensively used by those most interested in promoting the economic advantages of corn rootworm control. He concluded by saying, "We are gravely concerned with the high degree of variability associated with all rootworm evaluation criteria. Until more exacting criteria are available, our evaluations will include varied value judgments with the bias inherently associated with such guestimates."

Peters continued his studies to associate rootworm damage with corn yield losses and published several evaluation systems (Peters 1964a and 1964b, and Peters 1965). He referred to "root ratings" in the latter two publications, but he did not elaborate. He stated that root ratings were highly significantly correlated with yields, and he offered a negative correlation coefficient of -0.918 obtained from his soil insecticide trials in 1964 (Peters 1965). Ortman and Fitzgerald (1964) also stated that they had rated the root systems of different inbred lines for rootworm damage and regeneration of roots. Again, the rating system was not explained.

Musick and Fairchild (1967) established and explained a 1-to-6 rating scale to evaluate rootworm damage. However, their rating scale contained several subjective measurements, and the highest rating (6) was assigned to root systems with at least one node of roots destroyed. They employed two other rating scales to arrive at their "combined analysis root rating," and they considered this rating to be a good estimator of the performance of soil insecticides.

Petty et al. (1969) offered one of the first regression equations to explain corn yield loss attributed to corn rootworm larval infestations. They estimated that 0.8 percent yield loss per larva per plant occurred at a high level of infestation, and 1.4 percent yield loss per larva per plant occurred at a low level of infestation. These numbers were adjusted slightly if control was assumed to be 100 percent. They stated that the overall loss in yield caused by rootworm larvae could be computed by: yield loss = $0.001 + 0.765x$, where x = number of larvae per plant. In his review of corn rootworm literature, Chiang (1973) noted that the linear relationship reported by Petty et al. (1969) would not hold up if the rootworm population were extremely high. He added that the validity of this relationship would also be influenced by the date on which the larval population was sampled.

Munson et al. (1970) made the first reference to the 1-to-6 rating scale that is currently in use today. However, once again, the rating scale was not explained. They also mentioned a root recovery rating scale (1 to 5) that could be used to account for the corn plant's ability to grow more roots in response to rootworm larval feeding damage.

Finally, Hills and Peters (1971) published their explanation of the 1-to-6 root-damage rating scale that most entomologists are still using. They also presented a root-recovery rating scale that was based on the amount of root recovery above the damage zone. Their "adjusted root-damage rating" was obtained by subtracting the recovery rating from the damage rating. In their soil insecticide trials, root-damage ratings and adjusted root-damage ratings were negatively correlated ($r = -0.25$ and -0.32, respectively) to yield at the 1 percent level of confidence. Using their adjusted root-damage ratings, they developed a regression equation to estimate yield loss and found that for every unit increase in the adjusted root-damage rating, a reduction of 5.83 bushels per acre occurred. They considered this to be a reasonably conservative estimate of yield loss on the basis of other unpublished data at Iowa State University.

Turpin et al. (1972) established a root rating of 2.5 as the "economic injury level" for corn rootworm larval damage. Using yield data collected from many locations in Iowa, they found that damage ratings greater than 2.5 were linearly related to decreasing yields where a damage rating increase of 1.0 was associated with a 10-bushel-per-acre reduction in yield. Their final equation predicted economic damage where it did not occur at 5 percent of the study sites, and it predicted no economic damage where it did occur at 7 percent of the study sites. Although this represented a 12 percent error, the equation made correct predictions 88 percent of the time. Out of a total of 526 study sites where corn followed corn, their equation predicted that only 192 (36 percent) would have economic damage.

Apple et al. (1977) reported on a cooperative multistate project to measure the impact of corn rootworm larvae on corn yields. Investigators in seven midwestern states conducted similar experiments for one to four years. Each investigator used two corn hybrids and excessive amounts of Furadan to reduce rootworm populations below an economic level in one half of each hybrid plot. Data recorded included number of rootworm eggs per pint of soil, root-damage ratings, plant lodging, and yields. Only three of the cooperating states reported significant yield losses due to rootworms. However, their regression equation indicated that at five rootworm eggs per pint of soil, the loss in yield from subsequent larval attack would be 3 percent. In this publication they also introduced a 1-to-9 root-damage rating scale as being more sensitive to subtle differences in damage. Some entomologists use this rating scale rather than the 1-to-6 scale mentioned previously.

Chiang et al. (1980) used artificial infestations of different densities of rootworm eggs to measure the relationship between western corn rootworm populations and corn yield. Because naturally occurring rootworm infestations are not uniform in the field, all of the previously discussed studies had encountered considerable variations in results. Chiang et al. attempted to reduce the variation by utilizing the uniform distribution of eggs achieved with artificial infestation. They found that in both years of their study (1972 and 1973), yield was significantly reduced only when larval populations were so high, damage to the root system was so severe, and competition for food was so intense that the larvae suffered heavy mortality. This critical population level was higher when ample rainfall occurred and lower when the amount of rainfall was low. They stressed the importance of considering rainfall when assessing economic thresholds for western corn rootworms.

Foster et al. (1986) monitored a total of 118 cornfields in Iowa from 1979 to 1981 to evaluate the value of both rootworm beetle thresholds and root-damage rating thresholds for making rootworm management decisions. Using various regression techniques, they found that the root-damage rating threshold lacked the necessary degree of precision to account for much of the variation in yield loss. Root-damage ratings were not effective for predicting whether yield loss would exceed an economic level appreciably more than 50 percent of the time. The agronomic and edaphic factors they included in their final equation predicted root damage relatively well and yield loss rather poorly. Their root-damage ratings were not significantly correlated with yield loss.

Sutter et al. (1986) reported on four years of research in South Dakota during which they determined that yield reductions due to corn rootworm feeding were consistent over years and were affected by the level of rootworm infestation. However, they found that yield protection due to insecticide treatment occurred only at high rootworm population densities (root ratings of 4.5 or greater). In fact, they proposed that a "more realistic damage threshold for rootworms should be between 4.0 and 4.5." They added that the threshold would be subject to change depending on the price of corn, production costs, environmental conditions, soil type, and other variables.

This literature review reveals the serious effort that has been exerted to examine the relationship between rootworm larval damage and subsequent corn yield. Yet the relationship is still not clear, and indeed may never be thoroughly defined. It is obvious, however, that our current "economic injury level" for root-damage ratings is suspect. There are too many factors that affect corn yields and other variables that influence the determination of economic injury levels. Static economic injury levels fail to take dynamic conditions into account. In addition, the rootworm-corn plant interactions have not been thoroughly studied. Foster et al. (1986) concluded their paper by stating that the major emphasis of future corn rootworm research should be to delineate the factors affecting the relationship of rootworm damage and corn yield loss. If we are to accomplish this task, one area of research that requires attention is the study of the physiological responses of corn plants to rootworm larval damage for both nontreated corn and corn treated with soil insecticides. With this knowledge we would be able to answer more precisely the questions posed at the beginning of this section.

CORN ROOTWORM LARVAL DAMAGE STUDY, MONMOUTH, 1987

During our root-damage evaluations at Monmouth in July, 1987, we observed an extreme level of root regrowth on many of the plants in our trial. The greatest amount of regrowth usually occurred on the root systems that had been severely damaged by rootworm larvae. It appeared that most of the damage had been done to the innermost nodes of roots (the first nodes to grow). Because rootworm egg hatch occurred early in 1987, the nature of the damage to the earliest growing roots was not surprising. Regrowth around these damaged nodes obscured the amount of rootworm damage when the root system was first inspected. Many of these root systems had to be split in half with a knife in order to observe the extent of the damage. We also observed that the plants exhibiting a lot of regrowth had strong, upright stalks and apparently normally developing ears.

Because root regrowth is not accounted for in the standard 1-to-6 root rating scheme, we decided to collect additional data from this plot. Ten plants from each of seven treatment rows in each replication were dug, washed, and rated again in August. Each root system was marked individually so that measurements in addition to the root ratings could be made on the same plants. We measured the volume of each root system by using a water displacement technique, and then dried all of the root systems at air temperature for approximately two weeks. Each root system was weighed and the number of nodes from which roots had extended into the soil was recorded. In October, we hand harvested 1/1,000 of an acre from each of the treatment rows for which we had a full complement of data.

The results from this study had not been completely analyzed at the time this paper was being written. However, initial observations of the data suggest that there is no correlation between root ratings and yield. Appropriate results and analyses will be presented during the conference.

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Table 1. Corn Rootworm Soil Insecticide Evaluation, Urbana, Champaign County, Illinois, 1987

Product	Rate[a]	Method of application	Mean root rating[b,c]
SC-0567 10G	9	furrow	1.60 a
Fortress 10G	7.8	7-inch band	1.60 a
UBI-B8451 15G	4	7-inch band	1.70 ab
UBI-B8451 15G	6	7-inch band	1.75 ab
Dyfonate 20G (montmorillonite clay)[d]	6	7-inch band	1.75 ab
Fortress 10G	6	furrow	1.80 ab
XRD-429 2G	8	7-inch band	1.80 ab
Holdem	12	7-inch band	1.85 a-c
Fortress 15G	4	7-inch band	1.85 a-c
Dyfonate 20G	6	7-inch band	1.90 a-c
Counter 15G	8	7-inch band	1.95 a-d
Counter 15G	8	furrow	1.95 a-d
XRD-429 2G	16	7-inch band	1.95 a-d
XRD-429 2G	16	furrow	2.00 a-d
Force 1.5G	10	7-inch band	2.00 a-d
Fortress 10G	4.2	7-inch band	2.00 a-d
SC-0567 10G	12	furrow	2.00 a-d
Dyfonate 20G	6	furrow	2.05 a-e
Brace 10G	6	7-inch band	2.05 a-e
Broot 15GX	8	7-inch band	2.10 a-e
Fortress 10G	6	7-inch band	2.10 a-e
SC-0567 10G	6	furrow	2.10 a-e
Lorsban 15G	8	7-inch band	2.20 a-f
Furadan 15G	8	7-inch band	2.25 a-f
Force 1.5G	8	7-inch band	2.25 a-f
Aastar 15G	8	7-inch band	2.40 a-g
Holdem	6	7-inch band	2.45 a-g
Dyfonate 20G	3	7-inch band	2.45 a-g
XRD-429 2G	8	furrow	2.50 a-g
Mocap 15G	8	7-inch band	2.50 a-g
Counter 15G	4	7-inch band	2.50 a-g
Counter 15G	8	cultivation	2.65 b-h
XRD-429 2G	4	furrow	2.65 b-h
XRD-429 2G	4	7-inch band	2.65 b-h
SC-0567 10G	12	7-inch band	2.85 c-h
Lorsban 15G	8	split boot #1[e]	2.87 c-h
Thimet 20G	6	7-inch band	2.95 d-i
Lorsban 15G	8	furrow	2.95 d-i
SC-0567 10G	9	7-inch band	3.05 e-i
SC-0567 10G	6	7-inch band	3.05 e-i
Lorsban 15G	8	split boot #2[e]	3.13 f-i
SC-0567 10G	3	furrow	3.15 f-i
Lorsban 4E	2.5 fl oz	cultivation	3.40 g-j

(continued)

Table 1. (continued)

Product	Rate[a]	Method of application	Mean root rating[b,c]
Lorsban 15G	8	cultivation	3.50 h-j
Counter 15G	8	7-inch band[f] (no incorp.)	3.90 i-k
SC-0567 10G	3	7-inch band	4.15 jk
Furadan 15G	8	cultivation	4.45 kl
Check 3	...	...	5.05 l
Check 2	...	...	5.10 l
Check 5	...	...	5.15 l
Check 1	...	...	5.30 l
Check 4	...	...	5.30 l

[a]Rate expressed as ounces of product per 1,000 feet of row.
[b]Root damage rating scale includes six categories ranging from no damage (1) to severe damage (6). Mean is based on 20 observations (4 replications x 5 samples per replication).
[c]Means in a column followed by the same letter are not significantly different (Duncan's Multiple Range Test, $p = 0.05$).
[d]Montmorillonite clay carrier different from the carrier of the current formulation of Dyfonate 20G.
[e]Split boot applications made to two adjacent rows. See text for explanation.
[f]Insecticide applied behind the firming wheels of the planter. No incorporation tool was used.

Table 2. Corn Rootworm Soil Insecticide Evaluation, DeKalb, DeKalb County, Illinois, 1987

Product	Rate[a]	Method of application	Mean root rating[b,c]
Furadan 15G	8	7-inch band	1.55 a
AC-301468 20G	6	furrow	2.25 b
AC-301468 20G	6	7-inch band	2.25 b
AC-301467 23G	5.2	7-inch band	2.30 bc
Counter 15G	8	7-inch band	2.35 bc
Dyfonate 20G (montmorillonite clay)[d]	6	7-inch band	2.40 bc
Lance 15G	8	7-inch band	2.40 bc
Counter 15G	8	furrow	2.45 bc
Dyfonate 20G	6	7-inch band	2.60 b-d
Force 1.5G	10	7-inch band	2.65 b-d
Mocap 15G	8	7-inch band	2.75 b-d
AC-301467 23G	5.2	furrow	2.75 b-d
Lorsban 15G	8	7-inch band	2.90 b-e
Force 1.5G	8	7-inch band	2.95 c-e
Broot 15GX	8	7-inch band	3.15 de
Lorsban 15G	8	furrow	3.20 d-f
Aastar 15G	8	7-inch band	3.50 ef
Thimet 20G	6	7-inch band	3.80 f
Check 6	...	...	5.15 g
Check 3	...	...	5.30 gh
Check 4	...	...	5.35 gh
Check 2	...	...	5.40 gh
Check 1	...	...	5.70 gh
Check 5	...	...	5.85 h

[a]Rate expressed as ounces of product per 1,000 feet of row.
[b]Root damage rating scale includes six categories ranging from no damage (1) to severe damage (6). Mean is based on 20 observations (4 replications x 5 samples per replication).
[c]Means in a column followed by the same letter are not significantly different (Duncan's Multiple Range Test, p = 0.05).
[d]Montmorillonite clay carrier different from the carrier of the current formulation of Dyfonate 20G.

Table 3. Corn Rootworm Soil Insecticide Evaluation, Monmouth, Warren County, Illinois, 1987

Product	Rate[a]	Method of application	Mean root rating[b,c]
AC-301468 20G	6	7-inch band	1.90 a
UBI-B8451 15G	6	7-inch band	2.00 ab
Holdem	12	7-inch band	2.05 a-c
Lance 15G	6	7-inch band	2.05 a-c
Counter 15G	8	furrow	2.05 a-c
Counter 15G	8	7-inch band	2.10 a-d
XRD-429 2G	8	furrow	2.10 a-d
Furadan 15G	8	7-inch band	2.15 a-e
Holdem	6	7-inch band	2.15 a-e
UBI-B8451 15G	4	7-inch band	2.20 a-f
Brace 10G	6	7-inch band	2.20 a-f
AC-301467 23G	5.2	7-inch band	2.20 a-f
Lance 15G	8	7-inch band	2.20 a-f
Aastar 15G	8	7-inch band	2.25 a-f
AC-301468 20G	6	furrow	2.30 a-f
Dyfonate 20G	6	7-inch band	2.35 a-f
AC-301467 23G	5.2	furrow	2.35 a-f
Broot 15GX	8	7-inch band	2.45 a-f
Mocap 15G	8	7-inch band	2.45 a-f
Force 1.5G	8	7-inch band	2.45 a-f
Lorsban 15G	8	split boot #1[d]	2.50 a-f
XRD-429 2G	8	7-inch band	2.50 a-f
Force 1.5G	10	7-inch band	2.50 a-f
Dyfonate 20G (montmorillonite clay)[e]	6	7-inch band	2.50 a-f
Lorsban 15G	8	split boot #2[d]	2.65 b-f
Counter 15G	4	7-inch band	2.70 c-f
Thimet 20G	6	7-inch band	2.75 d-f
Lorsban 15G	8	furrow	2.80 ef
Counter 15G	8	cultivation	2.85 f
Lorsban 15G	8	7-inch band	2.85 f
Furadan 15G	8	cultivation	3.55 g
Furadan 4F	2.5 fl oz	cultivation	3.65 g
Lorsban 15G	8	cultivation	3.95 g
Lorsban 4E	2.5 fl oz	cultivation	4.60 h
Check 1	...	...	5.30 i
Check 2	...	...	5.35 ij
Check 5	...	...	5.60 ij
Check 6	...	...	5.75 ij
Check 4	...	...	5.80 ij
Check 3	...	...	5.95 j

[a]Rate expressed as ounces of product per 1,000 feet of row.
[b]Root damage rating scale includes six categories ranging from no damage (1) to severe damage (6). Mean is based on 20 observations (4 replications x 5 samples per replication).
[c]Means in a column followed by the same letter are not significantly different (Duncan's Multiple Range Test, $p = 0.05$).
[d]Split boot applications made to two adjacent rows. See text for explanation.
[e]Montmorillonite clay carrier different from the carrier of the current formulation of Dyfonate 20G.

Table 4. Corn Rootworm Soil Insecticide Evaluation, Bloomington, McLean County, Illinois, 1987

Product	Rate[a]	Method of application	Mean root rating[b,c]
AC-301467 23G	5.2	7-inch band	1.75 a
AC-301468 20G	6	furrow	1.90 a
Lorsban 15G	8	split boot #1[d]	1.95 a
Counter 15G	8	furrow	2.00 a
Lorsban 15G	8	split boot #2[d]	2.00 a
Counter 15G	8	7-inch band	2.05 a
Lance 15G	8	7-inch band	2.05 a
AC-301467 23G	5.2	furrow	2.10 a
AC-301468 20G	6	7-inch band	2.10 a
Dyfonate 20G (montmorillonite clay)[e]	6	7-inch band	2.20 a
Lance 15G	6	7-inch band	2.25 a
Thimet 20G	6	7-inch band	2.25 a
Dyfonate 20G	6	7-inch band	2.35 a
Broot 15GX	8	7-inch band	2.40 a
Lorsban 15G	8	furrow	2.45 a
Furadan 15G	8	7-inch band	2.50 a
Force 1.5G	8	7-inch band	2.50 a
Lorsban 15G	8	7-inch band	2.50 a
Force 1.5G	10	7-inch band	2.60 a
Counter 15G	8	cultivation	3.35 b
Mocap 15G	8	7-inch band	3.40 b
Aastar 15G	8	7-inch band	3.45 b
Mocap 15G	8	cultivation	4.70 c
Lorsban 4E	2.5 fl oz	cultivation	5.00 cd
Lorsban 15G	8	cultivation	5.05 c-e
Furadan 15G	8	cultivation	5.20 c-f
Check 3	...	...	5.60 d-f
Check 4	...	...	5.85 ef
Check 5	...	...	5.85 ef
Check 2	...	...	5.90 f
Check 1	...	...	5.95 f
Check 6	...	...	5.95 f

[a]Rate expressed as ounces of product per 1,000 feet of row.
[b]Root damage rating scale includes six categories ranging from no damage (1) to severe damage (6). Mean is based on 20 observations (4 replications x 5 samples per replication).
[c]Means in a column followed by the same letter are not significantly different (Duncan's Multiple Range Test, p = 0.05).
[d]Split boot applications made to two adjacent rows. See text for explanation.
[e]Montmorillonite clay carrier different from the carrier of the current formulation of Dyfonate 20G.

DIMBOA in Corn: A Preformed Chemical Defense Mechanism to Lesion Nematodes

L. Vaillancourt, T. Melton, and K. Simcox

INTRODUCTION

Lesion nematodes (*Pratylenchus* spp.) are the most common plant-parasitic nematodes associated with corn in the Corn Belt (Norton 1983). The common name for these nematodes comes from the necrotic lesions they cause when they penetrate and feed on roots. Lesion nematodes in excess of about 1000 per gram of corn root can cause serious yield losses. Fewer nematodes are needed to cause damage on less fertile soils or where there is moisture stress. Losses of up to 26 percent have been reported on sandy soils (Norton and Hinz 1976). Lesion nematode damage on roots also allows entry of various root-rotting fungi (Miller et al. 1963). Chronic infection probably causes significant yield losses each year, but the yield reduction may be too small to warrant expensive chemical treatments. It is important, therefore, to identify natural resistance mechanisms in corn that may be exploited through breeding programs.

DIMBOA (2,4-dihydroxy-7-methoxy-1,4 (2H)-benzoxin-3(4H)-one) is a phenolic compound that occurs bound to a sugar molecule in the cell vacuoles of corn tissue. If the tissue is damaged, enzymes cleave off the sugar molecule leaving a form of DIMBOA that is toxic to the first generation larvae of the European corn borer and to the corn leaf aphid (Klun et al. 1967; Klun and Robinson 1969; Long et al. 1977). DIMBOA is thought to play an important role in the resistance of corn to these pests. Different corn lines and different tissues within the same plant produce different amounts of DIMBOA. In 1964, Hamilton reported the discovery of a Gehu Yellow Dent corn mutant which produces one-tenth the DIMBOA of its parent line. The mutant is homozygous recessive for the *bx* allele. Most commercial corn inbreds are homozygous dominant for this allele. Since differential resistance of some corn inbreds to lesion nematodes has been reported (Georgi et al. 1983), and because we know that lesion nematode feeding results in the release of various phenolic compounds from root cell vacuoles, we became interested in the possibility that DIMBOA plays a role in the resistance of corn to lesion nematodes.

We have undertaken a breeding program to introduce the *bx/bx* genotype into commercial dent corn inbreds to compare them with their *Bx/Bx* parents for resistance to lesion nematodes. The nematode species we are using are *P. hexincisus* and *P. scribneri*, the two most common types found in Illinois corn fields.

MATERIALS AND METHODS

Both species of lesion nematode were increased on carrot disks according to the method of Lawn and Noel (1986). Seed of the Gehu Yellow Dent isogenic lines, of the commercial inbreds A632 and Oh43, and of the selfed F_2 generation of A632 or Oh43 crossed with the *bx/bx* Gehu Yellow Dent line, were germinated and then the root tips were crushed on filter paper soaked with a solution of ferric chloride. Ferric chloride reacts with DIMBOA to give a dark blue color. We selected five F_2 seedlings from each cross that did not produce the blue color, indicating that they were homozygous recessive for the *bx* allele. Five seedlings of each of the other lines were chosen at random, and all the seedlings were planted in four-inch pots containing a sterile soil mix (60 percent sand). The pots were placed on the greenhouse bench in a randomized complete block design with six treatments and five blocks. All the pots were inoculated with a suspension of nematodes (approximately 345 *P. hexincisus* per pot, or 1000 *P. scribneri* per pot). Plants were watered daily. After eight weeks, nematodes were extracted from the soil by sieving and from the roots in a mist chamber. The numbers of nematodes per gram of root, and the total number per pot, were recorded. Separate experiments were performed for each nematode species. The experiments were repeated once. When this paper was prepared, data was available from one experiment with each of the nematode species.

RESULTS

The histograms in Figures 1 and 2 summarize the results of this study. Significantly fewer nematodes of both species were recovered from corn lines with the *Bx/Bx* genotype when compared to the isogenic or near-isogenic lines with the *bx/bx* genotype (alpha = .10). The exception was *P. scribneri* on the isogenic Gehu Yellow Dent lines. The numbers of nematodes recovered were not significantly different in this interaction. It is possible that the high and low DIMBOA lines were misidentified. This was the only interaction for which the seedling phenotype was not checked with ferric chloride. The data may also indicate that there is a different relationship between the isogenic Gehu Yellow Dent lines and *P. scribneri*.

The findings presented here indicate that the absence of DIMBOA in the roots results in increased susceptibility of corn to the lesion nematodes *P. hexincisus* and *P. scribneri*.

We will continue to investigate the role of DIMBOA in the resistance of corn to lesion nematodes. It is expected that the numbers of nematodes recovered from the lines derived from our breeding program will be more divergent as homogeneity with the recurrent parent increases. We are screening other commercial corn inbreds and hybrids for lesion nematode resistance and for DIMBOA content. We are also examining the effects of DIMBOA on the nematodes in vitro.

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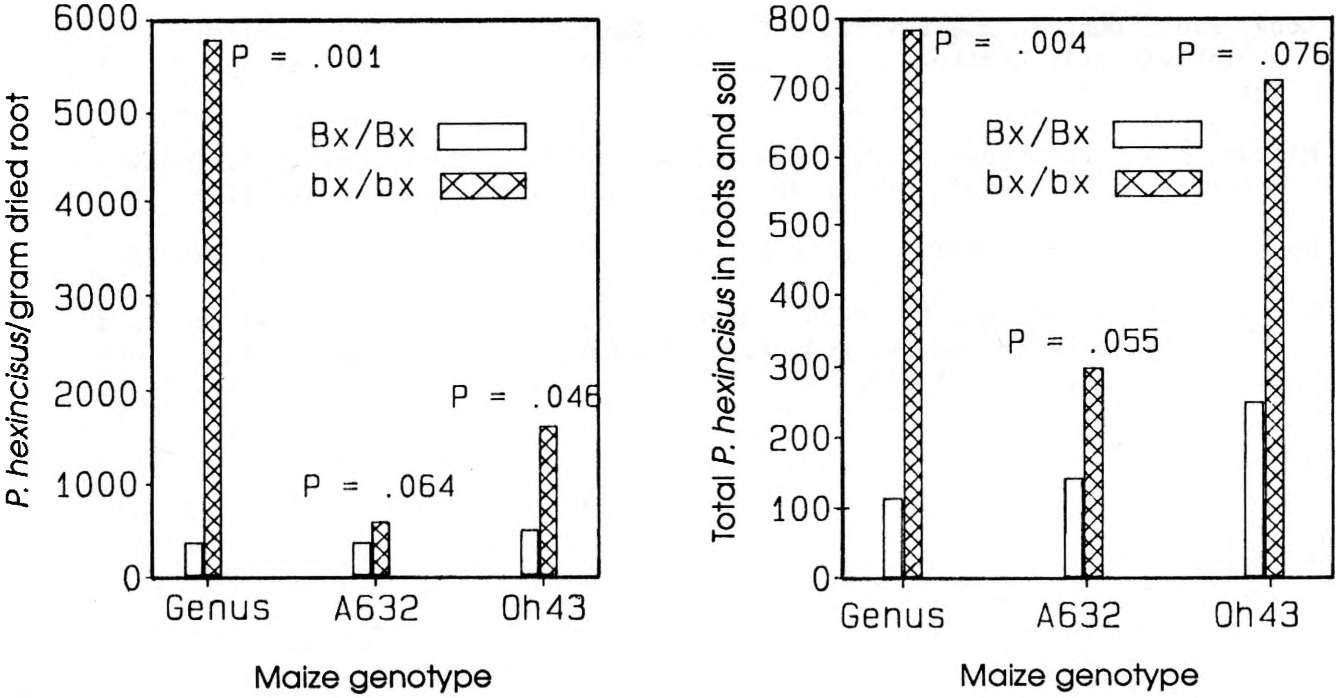

Figure 1. Relationship between maize genotype and susceptibility to Pratylenchus hexincisus.

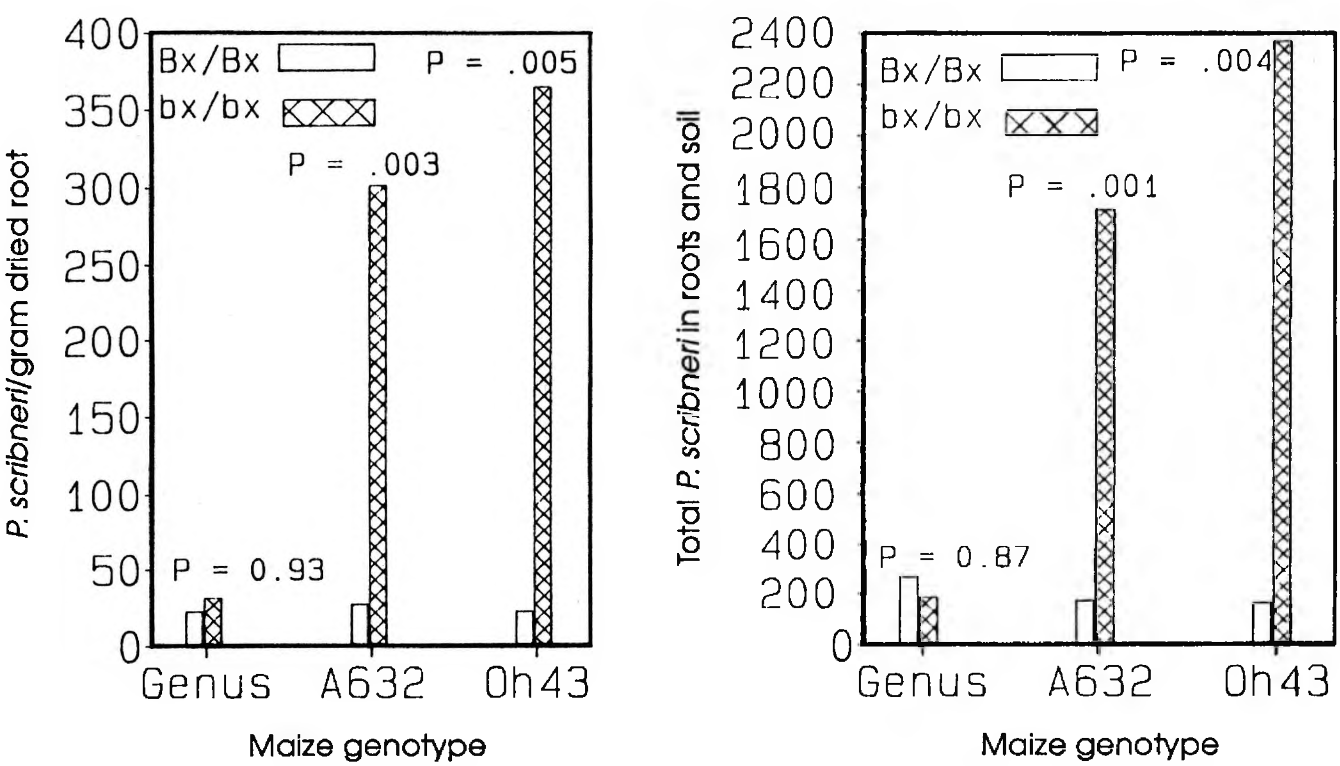

Figure 2. Relationship between maize genotype and susceptibility to Pratylenchus scribneri.

Weed Control for Conservation Tillage Systems

L. Wax and J. Hummel

The decision by a corn and soybean grower to adopt a conservation-tillage system is based upon the grower's assessment of the profitability of the conservation-tillage system as compared to his current tillage system. The actual conservation-tillage system chosen will depend upon the grower's perceived ability to manage his inputs of capital and labor as they interact with pests, climate, and soil to produce an increase in profit over that obtained from the current tillage system.

Adequate weed control is essential for profitable production of corn and soybeans. In reduced-tillage and no-tillage systems, much greater dependence is placed on herbicides to achieve weed control because the use of tillage for weed control is either reduced or eliminated entirely. Corn and soybean growers are interested in adopting alternative tillage and weed control combinations to reduce production costs and to control erosion. However, the adopted combination must have sufficiently high probability of high yields so that profitability is maintained or enhanced.

The results of a long-term, corn-soybean rotation tillage experiment to evaluate the effects of tillage and weed control combinations on weed pressure, plant growth, and yield are presented herein. The experiment was conducted over an eight-year period on Drummer silty clay loam and Flanagan-Catlin silt loam soils having a slope of less than 2.0 percent. The study included five tillage systems ranging from intensive- to no-tillage, and preplant incorporated (PPI), preemergence (PRE), and postemergence (POST) weed control alternatives. The study was initiated in 1979, and data from the 1980 to 1986 growing seasons have been analyzed. The data from the three intermediate-tillage systems were similar and were grouped together and labeled reduced tillage.

The tillage systems included in the experiment were:

1. **Intensive tillage.** After corn harvest, the land was disked and moldboard plowed in the fall. In the spring, the soil surface was leveled by disking, and a seedbed was prepared and herbicides incorporated by disking and field cultivating before planting soybeans. The crop was cultivated once. After harvesting soybeans, the tillage treatment was the same as after corn harvest, except a chisel plow was used in place of fall disking and moldboard plowing and corn was planted in place of soybeans.

2. **Reduced tillage.** Three systems utilizing a sweep plow, disk, or subsoiler-bedder were used for fall tillage following corn. The subsoiler-bedder was also used in the fall following soybean production. Spring tillage operations were similar to the intensive-tillage system.

3. **No tillage.** Corn was planted without preplant tillage. Soybeans were planted without preplant tillage, but corn stalks were shredded.

An effort was made to perform all operations at a time and in a manner appropriate for that system. All tillage was done when soil moisture conditions were favorable. Planting was accomplished as soon as weather, soil conditions, and scheduling permitted. Herbicides were selected for the main plots that could be applied PPI or PRE so that the same herbicides could be used with all tillage systems. Paraquat 2EC at 1 quart per acre (qt/A) was used as a burndown on the no-tillage plots for both corn and soybeans.

Subplots were used to compare PPI, PRE, and POST weed control alternatives. The PPI and PRE herbicides used on the soybean plots were Lasso 4EC at 3 qt/A plus Sencor 4L at 0.5 qt/A. For corn, the PPI and PRE herbicides used were Lasso 4EC at 3 qt/A plus AAtrex 4L at 2 qt/A. The POST herbicides for soybeans were Basagran at 0.75 qt/A and Poast at 0.67 qt/A. For corn, the POST subplots received either a PPI or PRE application of Lasso, depending upon tillage treatment, and a POST treatment of Basagran at 0.75 qt/A.

The tillage systems were evaluated on the basis of weed control, stand establishment, surface residue cover, soil nutrient profile, and yield. Data collected on weed control and yield have been summarized to illustrate the interaction of tillage system and weed control alternatives. Ranges of weed control are averages of grass and broadleaf control obtained by the PPI, PRE, and POST weed control systems.

Weed pressures in the soybean portion of the rotation (Figure 1) tended to increase during the first four years of the experiment, particularly in the no-tillage system. Soybean yields (Figure 2) were also reduced in some of the weed control systems. An exception was Year 3, when ideal rainfall resulted in sufficient soil moisture to support growth of both weeds and soybeans. (Excess application levels of fertilizer have made availability of nutrients unlimited.)

In Years 5, 6, and 7, an early preplant (EPP) application of Roundup at 0.75 qt/A was added to the no-tillage system. The range of weed control across weed control alternatives was reduced and the overall weed control improved so that weed control in the no-tillage system was equal to or better than that obtained in the reduced- and intensive-tillage systems. Soybean yields in Years 6 and 7 in the no-tillage system also equaled those obtained with intensive tillage and exceeded the yields obtained with the reduced-tillage systems.

Weed pressures in the corn portion of the rotation (Figure 3) tended to increase during the first five years of the experiment, although control was better than it was in the soybeans (Figure 1). Levels of weed control were generally lowest and ranges of weed control were largest in the no-tillage systems during these years. Corn yields (Figure 4) were lowered in the no-tillage system in Years 2 and 3 due to weed pressure. Exceptionally low yields in Year 4 were due to high temperatures that reduced pollination across all tillage systems. The addition of the EPP weed control practice in the no-tillage soybean system, beginning in Year 5, appears to have reduced the weed pressure in this system for the following years' corn. Corn yields and ranges of corn yields for Years 6 and 7 were nearly identical.

Summary

Adequate weed control is essential to maintaining high yields of corn and soybeans, regardless of tillage system. When conservation- or no-tillage systems are adopted on high yield potential soils, additional weed pressures can be expected. These pressures can be counteracted by chemical weed control alternatives to maintain the production levels associated with intensive-tillage systems.

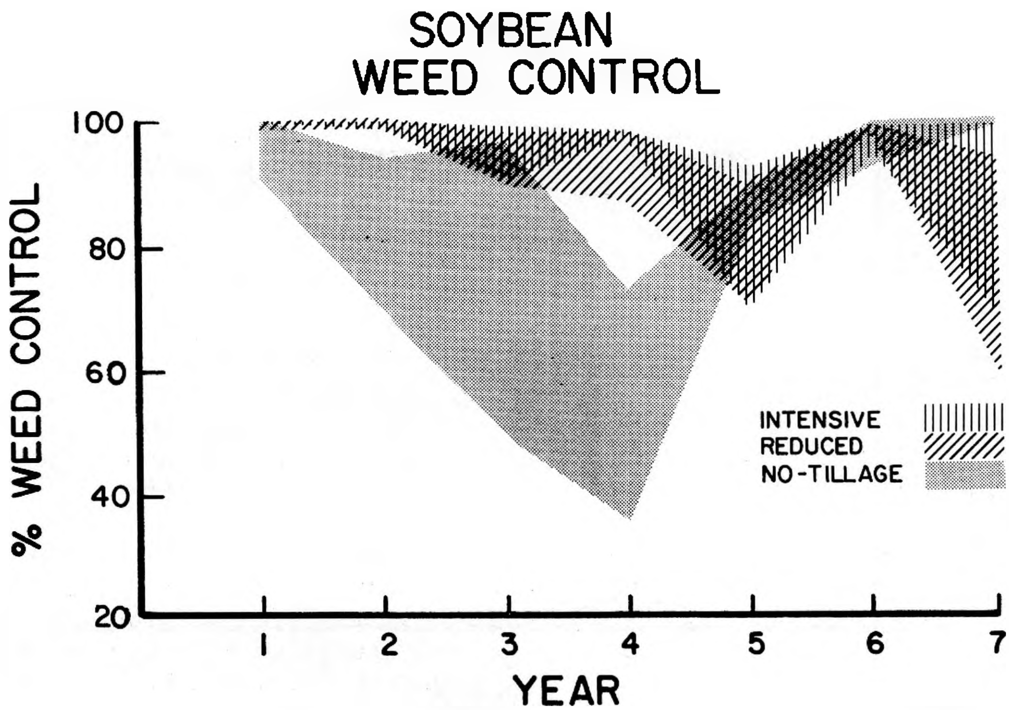

Figure 1. Weed control ranges (average of broadleaf and grass control) achieved in soybeans with each level of tillage include data from PPI, PRE, and POST weed control alternatives. Beginning in Year 5, an EPP application of Roundup was added to the no-tillage weed control system.

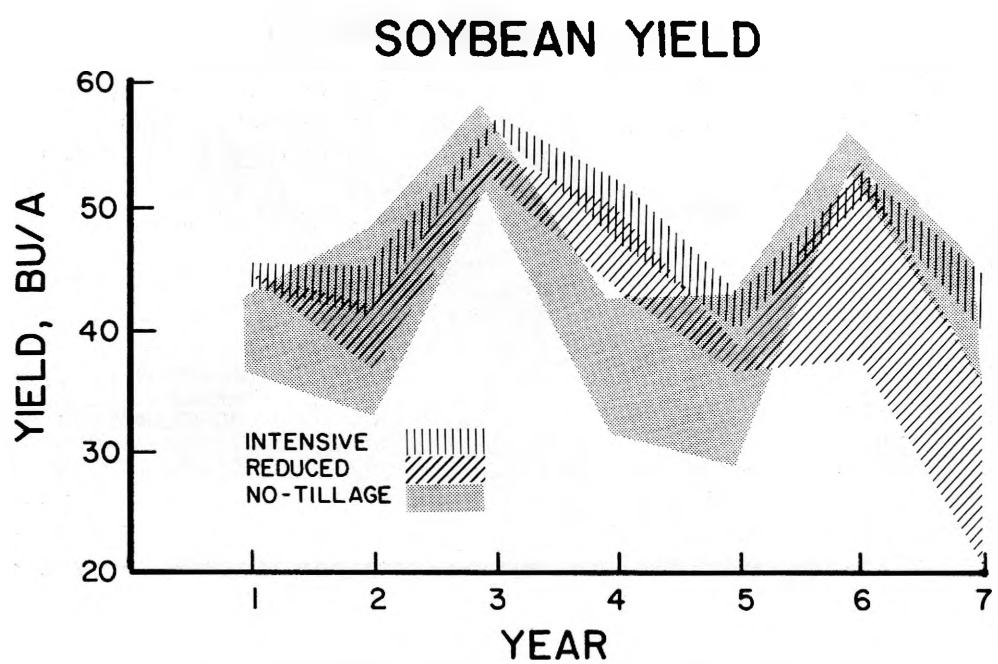

Figure 2. Soybean yield ranges achieved with each level of tillage include data from PPI, PRE, and POST weed control alternatives. All data are for 'Corsoy-79' cultivar seeded in 30-inch rows.

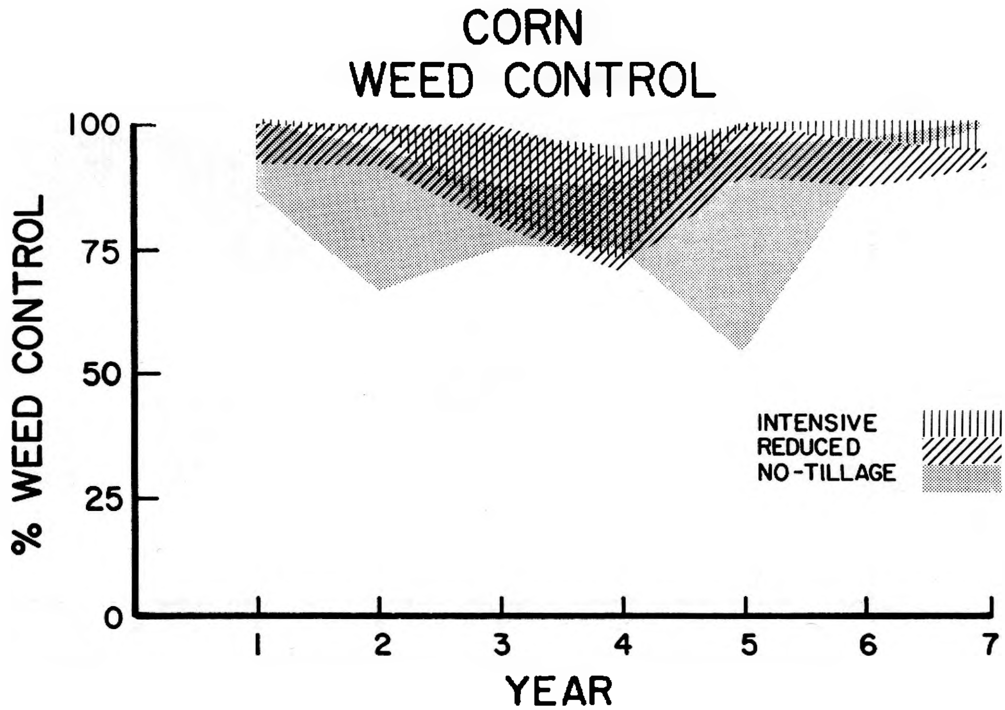

Figure 3. Weed control ranges (average of broadleaf and grass control) achieved in corn with each level of tillage include data from PPI, PRE, and POST weed control alternatives.

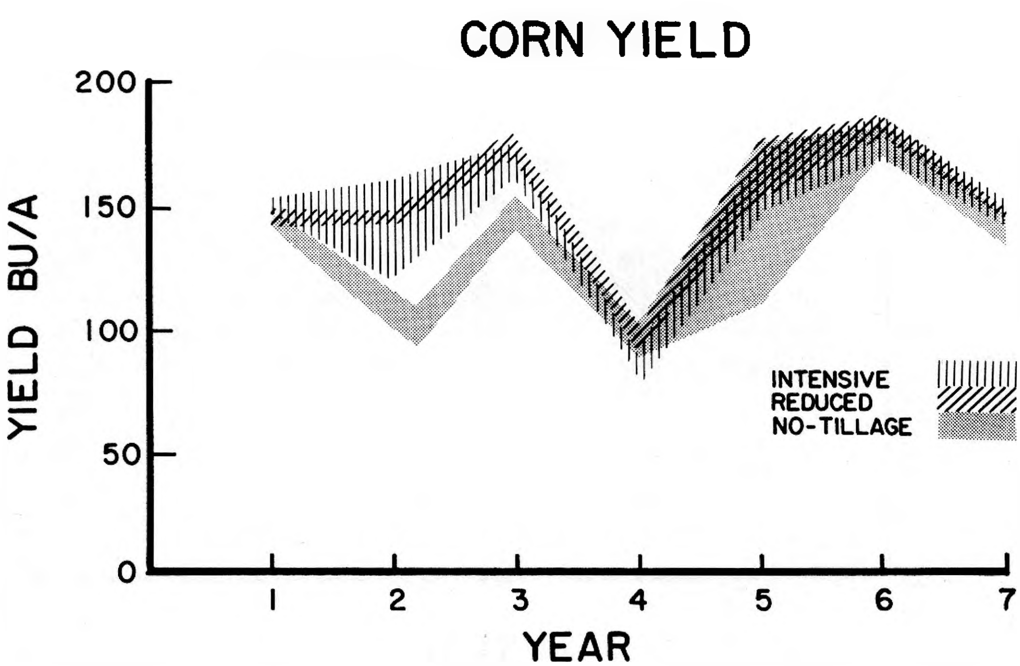

Figure 4. Corn yield ranges achieved with each level of tillage include data from PPI, PRE, and POST weed control alternatives. All data are for full season, single cross hybrids seeded in 30-inch rows.

Incorporation Techniques for Reduced Tillage Systems

S. Pearson, L. Bode, and L. Wax

INTRODUCTION

Preplant incorporated herbicides continue to play a large role in controlling weeds for row-crops. Numerous studies have explored the effectiveness of various incorporation tools for mixing herbicides in the soil. These studies indicate that the performance of soil-applied herbicides are dependent on the uniformity to which they are mixed in the soil profile.

The concept of reduced tillage adds a new dimension to the use of incorporated herbicides. Although reduced tillage has been shown to be effective in reducing soil loss and maintaining moisture due to crop residue, it is difficult to use preplant incorporated herbicides with reduced tillage practices. Most techniques that result in uniform mixing of herbicides do not leave sufficient crop residue on the soil surface to be effective for soil erosion control. The aim of incorporating herbicides in reduced tillage systems is to maintain an acceptable level of crop residue while uniformly distributing the herbicide within the soil profile.

The object of this study was to determine which incorporation tools provide acceptable weed control with a minimum amount of primary tillage and incorporation passes.

EQUIPMENT AND PROCEDURE

During the 1986 and 1987 growing seasons, several field studies were conducted to evaluate the effect of incorporation tools on weed control in both corn and soybeans. Tank mixes of herbicides were used to control grass weeds (giant foxtail) and broadleaf weeds (velvetleaf and pigweed). Two rates of herbicide tank mixes were used in the corn study. The first tank mix, Genate-Plus and atrazine (3.35 and 1.5 lb a.i./A), was applied to the plots disked prior to application; a rate of 4.2 and 1.5 lb a.i./A, was applied to the untilled plots of soybean stubble. As a comparison, a tank mix of Lasso and atrazine at rates of 2.5 and 1.5 lb a.i./A were applied on both predisked and undisturbed plots.

Four combinations of herbicide mixes were used in the soybean study. They included Treflan-Command, Treflan-Scepter, Sonalan-Command, and Sonalan-Scepter. Treflan and Sonalan were applied at a rate of 0.75 lb a.i./A, Command at a rate of 0.56 lb a.i./A, and Scepter at a rate of 0.094 lb a.i./A. All herbicide combinations and rates were used on both the predisked plots and undisturbed plots (corn stubble).

Four incorporation tools were evaluated in these field studies. In 1986, the surface blend tool was a Glenco soil finisher. This tool has one row of disk gangs in front, followed by four rows of danish tines and a heavy spiked-tooth harrow. In 1987, the surface blend tool was a John Deere rolling incorporator, a prototype consisting of two rows of 12-inch wide heavy cultivator sweeps, followed by two rows of rolling spiked cultivator wheels. In both years of this study, the same field cultivator and disk were used. The field cultivator has three rows of shanks with 7-inch sweeps, followed by a spiked-tooth harrow. The tandem disk has two gangs of 21-inch diameter blades at a 9-inch spacing.

Prior to the application of the herbicide treatments, half of the plots were disked for leveling purposes. The plots were then treated with a self-propelled plot sprayer at the designated herbicide rate. The incorporation treatment was then applied and the study was planted with either corn or soybeans.

RESULTS

Weed control ratings were taken several times during the growing season for both broadleaf and grass weeds. After half the plots received pre-tillage in the corn incorporation study, the herbicides and incorporation treatments were applied to these plots. Corn was then planted into the remaining soybean stubble. The same procedure was followed for the plots receiving no pre-tillage.

Table 1 indicates that for both years and all weed types, two incorporation passes with a disk provided the most consistent weed control. Two incorporations with a field cultivator in all but the 1986 velvetleaf ratings provided equally or almost equally good weed control as that of the two disk incorporations. The surface blend tool did not provide as consistent control as two passes with a disk or field cultivator but generally resulted in better control than one pass with a disk or field cultivator. There was no significant effect on the resulting weed control from disking the bean stubble prior to the incorporation passes, or from the two herbicide combinations. The higher herbicide rate on the undisturbed plots masked any effects due to tillage.

After half the plots received pre-tillage in the soybean incorporation study, incorporation and herbicide treatments were applied to the plots and soybeans were planted into the remaining corn residue. The same procedure was followed for the plots receiving no pre-tillage. Table 2 indicates that using two incorporation passes with a disk or field cultivator gave the most consistent weed control. The surface blend tool provided excellent velvetleaf control but foxtail control was not as good as two passes with a disk or field cultivator. One pass incorporation with a field cultivator resulted in the poorest control of all the tools evaluated.

In the 1986 study, the plots that were disked before herbicide application resulted in significantly better weed control than when applying the treatments directly on chiseled corn stalks. The 1987 study showed a substantial difference between the use of the herbicide Scepter as a tank mix with Treflan and Sonalan as opposed to Command. However, this finding was from only one year of data and should be repeated before conclusions can be made.

SUMMARY

These studies show that when incorporation passes are decreased, a slight decrease in weed control may occur. However, the benefits of leaving residue on the soil surface with the reduced incorporation may outweigh the slight decrease in weed control that may occur. The studies also indicate that herbicides can be applied directly to chiseled corn stalks or undisturbed soybean stubble with little or no reduction of weed control.

Table 1. Weed Control Results for Corn Herbicide Incorporation Study

Treatment	Foxtail control		Pigweed control	Velvetleaf control	
Average for incorpration tools:	1986	1987	1987	1986	1987
	percent				
Cultivator (2 passes)	81 a	87 a	89 a	83 b	78 a
Cultivator (1 pass)	65 c	75 c	82 b	64 d	63 bc
Disk (2 passes)	82 a	87 a	90 a	90 a	76 a
Disk (1 pass)	71 bc	85 ab	86 ab	73 c	69 ab
Surface blend	78 ab	77 bc	82 b	85 ab	58 c
Average for tillage prior to incorporation:					
Disk	75 a	84 a	86 a	79 a	67 a
Undisturbed	76 a	79 a	84 a	81 a	66 a
Average for herbicide mixes:					
Genate - atrazine	76 a	83 a	86 a	79 a	69 a
Lasso - atrazine	76 a	77 a	80 a	86 a	57 b

NOTE: Percent weed control ratings followed by the same lower case letters in a column are not significantly different at the 10 percent level.

Table 2. Weed Control Results for Soybean Herbicide Incorporation Study

Treatment	Foxtail control		Velvetleaf control	
Average for incorporation tools:	1986	1987	1986	1987
	percent			
Cultivator (2 passes)	81 ab	86 a	67 ab	69 a
Cultivator (1 pass)	72 b	72 d	50 b	60 b
Disk (2 passes)	91 a	82 ab	76 a	69 a
Disk (1 pass)	78 ab	76 cd	62 ab	67 a
Surface blend	78 ab	80 bc	67 ab	73 a
Average for tillage prior to incorporation:				
Disk	88 a	80 a	74 a	70 a
Undisturbed	71 b	79 a	58 b	67 a
Average for herbicide mixes:				
Treflan - Command	73 a	78 ab	63 a	70 b
Treflan - Scepter		81 a		79 a
Sonalan - Command	81 a	75 b	65a	58 c
Sonalan - Scepter		83 a		76 ab

NOTE: Percent weed control ratings followed by the same lowercase letters in a column are not significantly different at the 10 percent level.

Sudden Death Syndrome of Soybean: Current Research and Directions

S. Belmar, H. Kirby, and T. Melton

Sudden death syndrome (SDS) of soybean remains a mystery despite research efforts in several states. Researchers have reported that a fungus in the genus *Fusarium* is involved while others have reported a bacterium in the genus *Xanthomonas*. Sudden death syndrome of soybean research at the University of Illinois is focusing on the following aspects of the disease: etiology, epidemiology, and control.

During 1986, several attempts were made to identify the causal agent(s) responsible for the symptoms of sudden death syndrome. *Fusarium* and *Diaporthe* were the most prevalent fungi cultured from infected stem and root tissues. Unfortunately, in greenhouse and growth chamber pathogenicity tests, plants failed to produce representative symptoms of the disease when inoculated with any of these fungi. Likewise, naturally infested soil failed to yield symptoms on the SDS susceptible cultivars 'Williams 82', 'Fayette', 'Hobbit', and 'Uphoff 464'. The absence of environmental parameters (temperature and soil moisture) favorable for disease development were postulated to be responsible for the lack of symptom expression.

In 1987, one location in each of two counties, Pulaski and Clark, was selected for research to determine the effects of three cultivars, five chemical treatments, and two planting dates on sudden death syndrome incidence and severity. Plots were 10'x 50' and treatments were replicated three times. Three cultivars, 'Williams 82' (III), 'Fayette' (III), and 'Uphoff 464' (IV) were seeded at two different planting dates to establish early and late plantings. Chemical treatments included an untreated control and labeled rates of the following chemicals: methyl bromide (soil sterilant), Temik 15G (nematicide), Ridomil 5G (fungicide for *Pythium* and *Phytophthora*), and Terraclor 10G (fungicide for *Rhizoctonia*). All seeds were treated with Vitavax 200 to control damping off and with *Rhizobium* sp. to restore the nitrogen fixation capacity of plants in methyl bromide treated plots. Hygrothermographs were set up at each location to collect data on temperature and relative humidity. Soil samples were taken from each experimental plot prior to planting and at early pod-fill to determine the soybean cyst nematode (*Heterodera glycines*) populations. Plots were evaluated every two weeks for disease after plants were in a reproductive stage. Disease ratings (0 = no disease symptoms to 7 = complete defoliation) for each plot were based on a disease severity index developed at the University of Arkansas. The two center rows were harvested from each plot to evaluate seed weight and quality.

Disease was first observed on July 16 in the early planting and August 8 in the late planting in Pulaski County. Among the untreated checks, 'Uphoff 464' had the greatest disease severity rating. 'Williams 82' and 'Fayette' showed few disease symptoms which might be attributed to their maturity group. Tables 1 and 2 show mean disease ratings and mean cyst counts of soybean cyst nematode for preplant and early pod-fill soil samples taken from the plots. In Clark County, disease was first noted on August 13 and September 5 for the early and late plantings, respectively. Disease severity ratings were low for the untreated check of 'Uphoff 464' (range 0 to 1.75). Analysis of soybean cyst nematode samples from Clark County is in progress; however, to date the range of cysts is 20 to 38 cysts per 100 cubic centimeters of soil.

Results show methyl bromide to provide the best control. Although use of this chemical is not economically justified for soybeans, the chemical did provide circumstantial evidence that sudden death syndrome is a soilborne disease. The role of soybean cyst nematode remains undetermined because the data from Tables 1 and 2 do not demonstrate a definite relationship between soybean cyst nematode and disease ratings. A higher soybean cyst nematode population has been found at Clark County with a lower disease severity rating. Samples of SDS-infected plants from each location are being cultured to obtain the causal agent(s). Pathogenicity tests will be conducted on these cultured isolates in a growth chamber.

The preceding experiment will be repeated next year in order to substantiate the findings from this year. In addition, studies to monitor the spread of disease occurring in fields and throughout the state will be initiated.

Table 1. Chemical Effects on Sudden Death Syndrome of Soybean and Soybean Cyst Nematode for Early Planted 'Uphoff 464' Soybeans in Pulaski County

			Cysts per 100 cc soil			
	Disease	Rating	Preplant		Early pod	
Chemical treatment	mean	range	mean	S.D.	mean	S.D.
Control	5.42	5.00-6.00	0.67	0.61	6.27	5.08
Methyl Bromide	0.00*	0.00	0.00	0.00	0.13	0.23
Temik	4.67	3.00-6.00	0.40	0.40	0.53	0.46
Terraclor	3.67	2.50-5.50	0.80	1.06	14.90	21.70
Ridomil	5.25	4.50-6.00	2.13	1.40	11.10	9.43
Temik + Terraclor	3.08	3.00-3.25	2.27	2.95	2.13	3.03
Temik + Ridomil	4.33	4.00-5.00	0.13	0.23	1.33	2.31
Terraclor + Ridomil	4.42	2.25-6.00	0.27	0.46	6.27	9.18

NOTE: Data is based on the mean of three plots for each chemical treatment. S.D. is the standard deviation.
Disease rating scale: 0 = no disease symptoms; 1 to 2 = chlorotic spots on foliage; 3 = chlorotic and necrotic areas between foliar veins; 4 = necrotic areas between foliar veins and defoliation of upper nodes; 5 to 6 = necrotic areas with defoliation of upper nodes and pod abortion; 7 = complete defoliation of the plant yet petioles remain attached to stem of plant.
* Two plants in the center of one plot had chlorotic spots.

Table 2. Chemical Effects on Sudden Death Syndrome of Soybean and Soybean Cyst Nematode for Late Planted 'Uphoff 464' Soybeans in Pulaski County

			Cysts per 100 cc soil			
	Disease	Rating	Preplant		Early pod	
Chemical treatment	mean	range	mean	S.D.	mean	S.D.
Control	2.08	2.00-2.50	0.67	0.23	9.20	14.50
Methyl Bromide	0.00	0.00	0.27	0.23	1.30	1.29
Temik	0.00	0.00	0.13	0.23	0.53	0.23
Terraclor	0.75	0.00-1.75	0.93	1.01	8.13	6.35
Ridomil	1.00	0.25-2.75	0.40	0.40	0.27	0.46
Temik + Terraclor	0.08	0.00-1.60	0.53	0.92	0.40	0.40
Temik + Ridomil	0.83	0.75-1.00	0.40	0.40	2.67	2.57
Terraclor + Ridomil	1.75	0.50-2.50	0.27	0.23	0.80	0.80

NOTE: Data is based on the mean of three plots for each chemical treatment. Refer to Table 1 for more information.

Will My Computer Tell Me What To Do for Weed Control?

F. Baldwin

A pilot program for use as a guide when making weed management decisions in soybeans was released to county Extension agents and selected growers and consultants in 1986. Since that time, the program has been revised and will be available to the public in 1987. It runs on IBM or IBM-compatible computers. The program has five subprograms: (1) preplant and preemergence herbicide selection in conventional and conservation tillage systems; (2) over-the-top herbicide selection; (3) multi-species weed competition losses; (4) a combination of subprograms 2 and 3; and, (5) post-directed herbicide selection.

The program is designed to provide specific herbicide recommendations but not necessarily all possible recommendations that may provide control. Explanatory subroutines are provided at each place in the program where a question is asked or a decision must be made. After herbicides are selected, an economic analysis of each choice can be made using a predetermined price or any price the user may wish to enter. The weed competition program analyzes competition losses from any combination of species and densities entered. The losses are predicted as both yield and dollar losses based on anticipated yields and soybean prices. The program also forecasts consequences that would result from a failure to control a weed species.

The over-the-top herbicide selection recommends labeled rates and reduced rates where appropriate. It also allows the user to default to labeled rates if a reduced rate program is not desired. An economic analysis of each recommendation is provided for comparison to the competitive losses. The post-directed subprogram selects herbicides and provides for economic comparisons of selected herbicides.

Some Highlights of Weed Science Research in 1987

E. Knake

Many aspects of weed science research at the University of Illinois are being covered in other presentations. Hopefully, the information presented here will complement rather than duplicate the other presentations.

Weed Control for Corn

One of the greatest opportunities for reduced tillage with corn is for corn after soybeans. A tillage rotation with chisel plowing and secondary tillage for soybeans after corn, but liitle or no tillage for corn after soybeans, appears quite practical. One possibility is to simply apply herbicides such as Lasso, Dual, atrazine, and Bladex to soybean stubble and then plant, or plant first and then apply the herbicides. If early weed growth is present, Roundup, paraquat, Banvel, or 2,4-D may be added. Sutan+, Genate Plus, and Eradicane can be applied directly to the soybean stubble with tillage also providing control of existing vegetation. In our research, we have tried nearly all herbicides and have had very good weed control and good yields.

In trials, Marksman, Buctril-atrazine, and Laddock have given very good broadleaf weed control following a preemergence treatment for grass control.

Tandem with atrazine, Bladex, or both, performed quite well in our 1987 trials. Although this treatment has been promoted primarily for control of grass weeds, control of broadleaf weeds has also been quite good.

Continued research on fall panicum indicated again that tillage can enhance control. Preemergence herbicides such as Lasso, Dual, or simazine can provide initial control. Early postemergence treatment with Tandem plus Bladex can control escaped weeds while the use of Prowl can extend weed control further into the season.

Soybean Trials

Research results with Commence suggest the need to maintain adequate rates of Treflan for pigweed control and to avoid reducing Command rates too much if control of velvetleaf and other broadleaves is to be maintained. The Command plus metribuzin combination gives good control of most weeds except morningglory and is effective on cocklebur. However, there is potential for some soybean injury.

Although Scepter and Pursuit can be two of the most effective soil-applied herbicides on annual morningglory, control may not be complete. While Pursuit is more effective than Scepter on velvetleaf, both may need help from a herbicide such as Command.

A combination of a dinitroaniline, such as Treflan, plus Pursuit shows promise in controlling shattercane. Scepter and Pursuit continued to give good control of eastern black nightshade.

Corn is more sensitive to Scepter than it is to Pursuit, but the opposite is true for grain sorghum. With corn having greater tolerance to Pursuit than to Scepter, there appears to be less risk of carryover problems with Pursuit. Pursuit is also more effective than Scepter on some weeds. However, a Pursuit rate of 0.094 lb/A has appeared optimum for control of some weeds in our trials. Both Pursuit and Scepter exhibit marginal grass control.

Corn injury from Command carryover due to excessive rates or nonuniform applications can be very dramatic. However, corn generally outgrows the symptoms if not too serious. The effects of Scepter may be more subtle when plants are still green; however, some decrease in height and root stunting may be detected.

Preview can provide slightly better control of some broadleaf weeds than metribuzin due to the addition of chlorimuron. However, the browning of soybeans from the metribuzin can still occur. Our studies indicate that label precautions regarding soil pH will be important for Preview in avoiding carryover problems with corn. Because the amount of chlorimuron as Classic is much lower than the amount of soil-applied chlorimuron with Preview, the risk of carryover problems with Classic should be less. Preview would not be adapted to fields with a pH over 6.8.

One of the major weaknesses of Cinch is pigweed control. While a combination of Cinch and Preview is a possibility, the Cinch plus Pursuit combination was even better in one 1987 trial.

In one 1987 study, we attempted to delineate differences in postemergence rates of several soybean herbicides, including Scepter, Pursuit, and Classic for cocklebur, morningglory, and velvetleaf control. While reduced rates of Scepter may be adequate for cocklebur control, best control of the weed spectrum was with the labeled rate of 0.125 lb/A, or one gallon for 12 acres. Pursuit was generally better than Scepter in this trial on morningglory and velvetleaf, although control was not complete with either. Some advantages of residual control were noted with Scepter, Pursuit, and Reflex. For Basagran plus Blazer combinations, reducing the rate of Blazer too low resulted in unsatisfactory morningglory control. In trials with Poast, Dash performed well.

Corn and Soybeans No-Till in Wheat and Rye

The question has been raised as to how to kill wheat or rye where they are used as cover crops or where the stand is reduced due to winter injury. For corn, atrazine alone was not as good as atrazine plus Gramoxone. The premix of Colonel, containing paraquat and atrazine, did well. Bladex was not as good as atrazine. One lb/A of Roundup appeared to be the optimum rate, with some reduction in control noted as the rate was reduced further. However, degree of control with lower rates may sometimes be acceptable. Ignite was not as effective as Roundup in this trial. From among the new postemergence grass killers, Fusilade, Verdict, and Assure generally performed best for killing wheat.

Corn and Soybeans in Oat Mulch

Where oats are used for set-aside and allowed to reseed to form a dense growth for an overwinter mulch, there is potential for planting no-till corn or soybeans. With corn, two of our best panicum control treatments were Conquest and Eradicane impregnated on dry fertilizer. For soybeans, Lasso EC or MT, Dual, and Cinch all performed well with Preview.

No-Till Corn in Alfalfa or Clover Sod

For killing shallow-rooted red clover, Bladex plus atrazine in a 1:1 ratio, Extrazine, and Conquest performed in a similar manner and gave about 70 percent control of clover with relatively dry conditions. A sequential application of Banvel at 0.25 lb/A completed the kill. For deeper rooted alfalfa, a combination of about 0.5 lb/A, 2,4-D ester and 0.25 lb/A Banvel has generally been adequate.

No-Till Soybeans

Overall, weed control for no-till soybeans has been a little more of a challenge than for no-till corn. Considerations must be made for both burndown and residual control of grass and broadleaf weeds. Results suggest that Verdict and Select may be effective for burndown and residual control. However, neither are commercially available. Roundup or Gramoxone have given good burndown of the majority of weed species.

Poast and Fusilade are additional options for grass control. In our studies, Preview performed better than Lorox Plus. Bladex also continued to perform well but is not yet registered for this use. Lasso, Dual, and Cinch exhibited adequate residual grass control.

Weed Control for Establishing Legumes

We continued to have excellent success with herbicides such as Poast, Fusilade, Whip, Select, Assure, and Verdict to control grass weeds for establishing clover and alfalfa. In addition to 2,4-DB, postemergence applications of Pursuit showed some broadleaf weed control.

In an effort to reduce cost of legume seed for set-aside acreage, we worked with ladino and alsike clovers. While their use may be feasible if significant care is taken in seeding, alfalfa and red clover have generally been easier to establish.

For weed control in established alfalfa and red clover, several herbicides may have potential but not be needed if a good competitive stand is established initially.

The Biology of Perennial Weeds

M. Horak

Perennial weeds are weeds that live for three or more years. They can reproduce sexually (by seed) or asexually (by tubers, stolons, rhizomes, etc.) In the past, perennial weed infestations were kept under control by standard farming practices that included intensive cultivation. The more recent trend toward reduced-tillage, however, has allowed perennial weed infestations to increase in frequency and severity. To combat these troublesome weeds and develop improved weed control strategies, an intensive study of perennial weed biology has been undertaken.

With the implementation of any control program, it is necessary to evaluate the program's effectiveness at various stages of weed development. Control effectiveness by herbicides and/or cultivation is dependent upon plant growth stage. For perennial plants there are six growth stages, including: seedling, vegetative, flowering, mature vegetative, dormant, and regrowth. At each stage different degrees of weed control can be expected from similar weed control treatments.

SEEDLING

The seedling stage is characterized by the germination of the seed and emergence of the seedling. This seedling is often most susceptible to control. Young plants that have not yet developed perennial structures will not regrow once they are killed.

VEGETATIVE

As the seedling continues to grow it passes into a vegetative stage. This stage is characterized by a rapid growth of the roots and shoots. Non-sexual propagation may result in the establishment of new plants during this stage if the plants produce stolons and rhizomes. In general, perennial weeds are not as susceptible to control measures at this time as they are at later stages. This is because the plants are growing rapidly and have adequate root and shoot reserves, which enable them to outgrow herbicide effects or resprout after herbicide application.

FLOWERING/SEED PRODUCTION

After the vegetative stage, a plant enters a reproductive phase. During flowering, perennial plants begin to channel their food reserves to the flowering structure from the root structures. Because of this, the plant is in a weakened state and weed control may be more effective. Control is also desirable at this stage to reduce spread of the weed by reducing or eliminating seed production.

MATURE VEGETATIVE

As the weed grows out of the flowering stage, it begins a vegetative stage in which the plant stores food for overwintering. During this stage, production of storage organs, for example, tubers, rhizomes, bulbs, and expanded roots, continues. For some perennials this is a good stage to attempt control, as the flow of photosynthetic products from the shoots to the storage organs carries a herbicide to these organs and good control often results. However, because some weeds are not able to move herbicides to the storage organs, variable results may be observed at this stage.

DORMANT

As the season progresses, the tops of perennial plants may die back and enter a dormant stage. Control with herbicides during this stage is not effective because there is little or no herbicide uptake. Some control may be obtained by cultivation of some species, provided the weed propagules are killed during the tillage.

REGROWTH

After overwintering, sprouts from the previous year's perennial structures may appear. As with seedlings, these sprouts are best controlled at an early stage. When sprouts first emerge there is a net flow of storage products out of the storage organ to the growing roots and shoots. This results in a reduction of food reserves; continued control practices during this stage can result in weed death.

It is important to understand that the effectiveness of control measures depends greatly on the stage of plant development. Although certain stages may overlap or be absent altogether, the important point to remember is that weed control should be practiced when the weed is in a weakened state.

As was briefly mentioned in the previous discussion, a weed may produce perennial structures that are varied in form and function. In order to further understand perennial biology and its effects on control measures, it is important to understand the mechanisms by which plants overwinter and spread. Methods of propagation by perennial plants include the following: seed, stolons and runners, rhizomes, tubers, bulbs, roots and budding roots, stems, and fragmentation.

Seed

In many cases seed is a means by which perennials spread and overwinter. Although the seed are not perennial structures, some perennial species produce abundant viable seed, resulting in the spread of an infestation. A common example would be johnsongrass, which has underground perennial structures for spread and overwintering (rhizomes) but also produces many viable seed.

Stolons and Runners

Stolons and runners are stems that grow along the soil surface and produce roots and shoots at the nodes. Because these structures grow above ground, they are generally not overwintering structures. Bermudagrass is an example of a weed with these structures.

Rhizomes

Rhizomes are similar to stolons in that they produce shoots and roots; however, they are horizontal underground stems. Johnsongrass is an example of a weed with this kind of structure. Rhizomes can result in shoot and root growth in the year of development as well as become overwintering structures.

Tubers

Tubers are the enlarged terminal ends of rhizomes. They are storage organs and may have several axillary buds. Tubers can germinate and grow in the season in which they develop or they may overwinter and produce growth the following season. Yellow nutsedge is an example of a plant that propagates by tubers.

Bulbs

Bulbs are modified buds with fleshy and scaly leaves, usually occurring underground. Like tubers, they may sprout during the season in which they develop or they may overwinter. Wild garlic is a weed that produces bulbs.

Roots and Budding Roots

These roots may grow horizontal to the surface or form large storage organs. At developed buds along the roots, the plant may send up a shoot and form a new plant. Roots of some species will not send up shoots until disturbed or cut apart. Examples of these include bigroot morningglory and Canada thistle.

Stems

Some plant species produce stems that can form adventitious roots and establish a new plant when in contact with soil.

Fragmentation

Some species of plants have leaves and stems that can sprout roots or shoots to produce new growth after being broken from the parent plant. Purslane is an example of a plant with this ability.

The growth stage and structure of perennial weeds can have an influence on control of a given species. With proper understanding of weed biology, good weed control can be obtained.

Clopyralid and Fluroxypyr for Control of Hemp Dogbane and Common Milkweed

M. Orfanedes and L. Wax

Perennial weed problems have been on the increase in the midwestern corn belt in recent years. Changes in tillage, crop rotation, and herbicide programs may be partially responsible for such shifts in the weed spectrum. Hemp dogbane (*Apocynum cannabinum)* and common milkweed (*Asclepias syriaca)* are examples of two perennial broadleaf weeds that are becoming increasingly prevalent in Illinois. Currently, few herbicide programs are available for consistent control of these species in corn.

Clopyralid and fluroxypyr are two relatively new compounds being developed by Dow Chemical Company for postemergence broadleaf weed control. This paper presents findings from a study that investigated the efficacy of these two compounds as postemergence treatments for control of hemp dogbane and common milkweed in corn.

In the study, applications were made in early June when the weeds were in the bud stage and corn was twenty to twenty-four inches tall. Treatments consisted of various rates of clopyralid and fluroxypyr and several herbicide combinations--some including 2,4-D or dicamba. A complete list of treatments is provided in Table 1. Treatments were applied with hand-held equipment and the spray solution was applied in a volume equivalent to 18 gallons per acre (See Table 1).

Control of hemp dogbane was generally excellent with all rates of fluroxypyr tested. 2,4-D and dicamba provided some control of hemp dogbane while clopyralid exhibited very little activity.

Control of common milkweed was considerably more difficult. Fluroxypyr provided some control at higher rates or in combination with dicamba or 2,4-D. Dicamba alone also showed considerable activity, although somewhat less than when tank-mixed with fluroxypyr. Clopyralid or 2,4-D alone generally resulted in poor weed control.

These results indicate the potential for improving control of hemp dogbane in corn. Although control of common milkweed was not nearly as impressive as hemp dogbane control, tank mixes of dicamba and fluroxypyr show promise as possible control methods.

Table 1. Control of Hemp Dogbane and Milkweed with Various Combinations of Clopyralid and Fluroxypyr

		Weed Control			
	Rate	Hemp Dogbane		Common Milkweed	
Treatment	(oz ai/A)	06-26	08-05	07-01	08-07
		percent			
clopyralid+ fluroxypyr	0 2	98	99	40	25
clopyralid+ fluroxypyr	0 4	99	97	73	63
clopyralid+ fluroxypyr	0 8	100	98	77	72
clopyralid+ fluroxypyr	2 0	11	16	31	36
clopyralid+ fluroxypyr	2 2	98	94	53	40
clopyralid+ fluroxypyr	2 4	100	95	65	55
clopyralid+ fluroxypyr	4 0	11	15	31	33
clopyralid+ fluroxypyr	4 2	76	96	45	43
clopyralid+ fluroxypyr	4 4	99	96	58	67
clopyralid+ fluroxypyr	8 0	11	13	34	42
clopyralid+ 2,4-D amine	2 4	69	87	33	35
clopyralid+ 2,4-D amine	4 4	58	68	35	34
clopyralid+ dicamba	2 4	50	70	54	68
clopyralid+ dicamba	4 4	54	82	53	68

(continued)

Table 1 (continued)

		Weed Control			
	Rate	Hemp Dogbane		Common Milkweed	
Treatment	(oz ai/A)	06-26	08-05	07-01	08-07
		---------------*percent*---------------			
fluroxypyr+ 2,4-D amine	2 4	96	97	46	42
fluroxypyr+ 2,4-D	4 4	100	100	68	69
fluroxypyr+ dicamba	2 4	99	99	74	68
fluroxypyr dicamba	4 4	95	96	76	72
2, 4-D amine	4	80	70	17	15
dicamba	4	62	88	55	67
weedy check	--	0	0	0	0

NOTE: All treatments included X-77 as surfactant at 0.25 percent volume/volume.

Bugs, Corn, and Set-Aside Acres

D. Kuhlman

According to officials with the State Agricultural Stabilization and Conservation Service (ASCS) Office, about 3.5 million acres were seeded to set-aside cover crops in Illinois in 1987. The Illinois Agricultural Statistical Service reported that almost two million of these acres were seeded to oats as the cover crop and, in many fields, with a legume underseeding.

A question likely to be raised by many farmers this winter will be, "What insect problems can I expect if I plant corn or soybeans on my set-aside acres in 1988?" To answer this question, the farmer must carefully analyze several variables that affect populations of insect pests.

In the event that a farmer is confronted with a greater probability of soil insect pests in corn planted after set-aside acres, two other questions are raised. These are, "Should I use a soil insecticide?" and "If so, which soil insecticide should I use?" This paper will address all three questions and attempt to assess the potential for insect problems in corn and soybeans after set-aside acres.

Based on the research and experience of Extension and research entomologists, it is unlikely that a major insect problem will develop in corn or soybeans planted in a field that has been in a set-aside cover crop for only one year. The chances of a single insect, or several insects, becoming an economic problem will depend largely on the influence of three factors: (1) the crop that was planted as a set-aside the previous year; (2) the type and timing of the tillage operation; and, (3) weather conditions this winter and next spring. Basically, the farmer needs to consider the previous set-aside crop for each field before making insect management decisions for corn or soybeans.

A review of research conducted by Illinois entomologists in the 1950s provides some insight into the relationship between insect infestations and crop rotation. Bigger and Petty (1965) studied population densities of soil insect pests from 1954 through 1963 in 452 Illinois fields. During the 10-year period, they found that wireworms were most likely to be important as a pest of corn following grass, clover, or alfalfa. Corn root aphids appeared most commonly where corn followed permanent grass sod; white grubs were more prevalent on corn following soybeans or grass sod. The grape colaspis was more abundant on corn following clover. Bigger and Petty concluded that in determining the need to control insects attacking first-year corn in a rotation, greatest consideration should be given to corn grown following grasses. They also reported that, regardless of rotation, 55 percent of the fields were attacked by two or more insect species. Equally important in their research was the fact that 21 percent of the fields were not infested.

Cropping sequences utilized by farmers in the 1950s usually included a legume or grass, which differs substantially from the predominantly corn-bean and corn-corn rotations of the 1980s. However, the current government program requires farmers to leave a summer cover on their set-aside acres, frequently a grass or legume, bringing about a return to the cropping sequences that were used by farmers in the '50s.

Based on the data of Bigger and Petty, Illinois Extension entomologists have compiled some estimates of the probability of occurrence of soil insect pests in corn on the basis of cropping sequence (Table 1). These estimates will provide a basis for the grower to put the potential for soil insect pests into better perspective.

Following are some guidelines for managing soil insect problems in corn after set-aside acres and suggestions for their control.

CORN AFTER SMALL GRAINS

Many fields were seeded to oats as a cover crop for the set-aside program in 1987. Winter wheat seeded in the spring was also used for cover. It is difficult to predict which insect pests might affect corn in this situation in 1988, let alone their abundance, but in general, the potential for infestations of wireworms, cutworms, and seedcorn maggot infestations is low.

In the northern half of Illinois, growers should be wary of corn rootworm damage to corn following small grains, particularly in fields where blooming weeds were plentiful last August and September. In some fields of small grain, weeds such as foxtail and ragweed became the dominant cover during late summer. The weed cover in the oat stubble fields may have attracted egg-laying northern corn rootworm beetles from adjacent fields of corn. A study by Shaw et al. (unpublished, Illinois Natural History Survey) in 1978-79 indicated that the risk of economic rootworm damage to corn following a small grain was less than one in thirteen.

Recommendations

In most fields, a diazinon + lindane planter-box seed treatment is the best option for planting corn after small grains. For less than one dollar per acre, the planter-box seed treatment will control wireworms and seedcorn maggots. If broadleaf weeds were blooming during August and September, there's a possibility that corn rootworm beetles were attracted to these fields for egg laying. This would be most likely to occur in northern Illinois where rootworm beetle populations were greatest. However, the application of a corn rootworm soil insecticide at planting is probably not warranted if the set-aside acres were clipped during early August, thus reducing the attractiveness of the field to rootworm beetles for egg laying.

CORN AFTER LEGUMES

Black cutworms, claybacked cutworms, dingy cutworms, and grape colaspis occasionally damage corn planted after clover or alfalfa. Although rootworm damage to corn after legumes is infrequent, northern corn rootworm adults are sometimes attracted to blooming legumes or to blooming weeds in legumes, where they feed and subsequently lay eggs during August and September.

Infestations of white grub and wireworm should be minimal in corn planted after a legume. It is unlikely that these pests, which have a three- to five-year life cycle, would increase to economic levels in a single year. If white grubs are evident during spring tillage operations, growers should take time to determine whether the species is the annual white grub or the true white grub. The latter species will damage corn; the annual white grub rarely causes problems.

Seedcorn maggots also pose a potential threat to corn planted in a legume. Large amounts of decaying vegetation from the legume cover crop could be very attractive to adult seedcorn maggots for egg laying in the spring. The grape colaspis is another soil insect pest that needs to be considered in corn following red clover. The adult, a beetle, lays her eggs in legumes, primarily red clover. The insect overwinters as a larva in the soil. Although none of the soil insecticides are labeled for grape colaspis, those that control white grubs should also give some control of this insect.

In fields where tillage is delayed until spring, the potential for black cutworm damage will increase, particularly if the appearance of legume and weed vegetation coincides with black cutworm moth flight.

Recommendations

A diazinon + lindane planter-box seed treatment is a good, low cost option for preventing damage by wireworms and seedcorn maggots in corn after a legume. This treatment should be supplemented with scouting for cutworm damage as the corn emerges. If a soil insecticide is to be applied, the grower should select one that will control the wireworm, white grub, and cutworm complex.

SOYBEANS AFTER SMALL GRAINS OR LEGUMES

With the exception of corn rootworms, soil insects that attack corn (wireworms, cutworms, white grubs, grape colaspis, and seedcorn maggot) can also damage soybeans. Fortunately, infestations of these pests are seldom large enough to inflict economic damage on soybeans, and application of soil insecticides is rarely justified. Soybeans, more so than corn, have the ability to compensate for some stand reduction without a subsequent loss of yield. Interestingly, the seedcorn maggot has been the soil insect pest most often encountered by growers in soybeans. In perspective, less than 1 percent of the soybeans in Illinois are affected annually by this seed pest. Problems have usually occurred where soybeans were planted in fields with an extensive vegetative cover of legumes or weeds. The decaying vegetation, particularly in fields not tilled until the spring, may be very attractive for egg laying by the flies.

In 1987, several fields of soybeans planted after set-aside acres were damaged by grape colaspis larvae feeding on the roots of newly emerged beans. The adult grape colaspis, a tan, elliptical beetle about one-sixth of an inch long, was probably attracted to lay eggs in fields that had legumes or smart weeds in the summer of 1986.

Recommendations

If soybeans are to be planted in a field that has large amounts of decaying vegetation, such as legumes, and no fall tillage was preformed, a planter-box seed treatment of diazinon + lindane will help protect the soybean seed from attack by seedcorn maggots and wireworms. With a few rare exceptions, neither a soil insecticide nor a planter-box seed treatment will be necessary on soybeans planted in set-aside acres. The only soil insecticides registered for application to soybeans at planting time are Lorsban 15G and 4E (for cutworms), Thimet 20G (for seedcorn maggots), and Furadan 15G (for nematodes). Lorsban 4E, Pydrin 2.4EC, Larvin 3.2F, and Asana 1.9EC are labeled as rescue treatments for cutworms.

Growers should avoid using the organophosphates Lorsban and Thimet in fields treated with the herbicide metribuzin (Sencor, Lexone). A warning statement on the labels of Sencor and Lexone indicates that crop injury may occur when preplant incorporated or preemergence applications of metribuzin are used in conjunction with soil-applied organophosphate insecticides.

CHOOSING A SOIL INSECTICIDE FOR CORN AFTER SET-ASIDE ACRES

Should I use a soil insecticide? What soil insecticide should I use? Can I get by with a planter-box seed treatment? These are some of the questions that farmers have asked county Extension advisers, pesticide dealers, pest management consultants, farm managers, and Extension entomologists. The management decision for controlling insect pests on corn after set-aside crops will depend on the degree of risk that a farmer is willing to accept. The probabilities for various soil insect pests in corn after cover crops are a starting point (Table 1). After examining the potential for the various soil insect pests, the farmer may elect to apply a soil insecticide at planting. Table 2 lists some of the soil insecticide alternatives for controlling soil insect pests of corn.

NO-TILL CORN IN SET-ASIDE CROPS

Corn no-tilled into set-aside crops may be subject to attack by several insect pests, depending on the preceding crop. Special consideration should be given to the control of cutworms, stalk borers, and armyworms in no-till corn after grass or legumes.

Cutworms

Some of the set-aside crops provide attractive egg-laying sites for cutworm moths. For example, female moths of claybacked, dingy, and variegated cutworms are attracted to legumes and legume/grass mixtures to lay eggs in the summer. These cutworm species overwinter as partially grown worms and attack newly emerging corn the following spring. Set-aside crops of legumes and grasses can also provide attractive egg-laying sites for black cutworm moths in the spring. All cutworm species might be controlled with a planting-time treatment of a soil insecticide. Scouting the field as the corn emerges should also enable the grower to make a timely rescue treatment.

Armyworms

Armyworm moths lay their eggs on grasses during April and May. The most severe armyworm infestations and damage usually occur in no-till corn planted in grasses. After the existing grass cover is killed with herbicides, newly hatched armyworm larvae attack the seedling corn plants. Successful management of armyworms in no-till corn requires scouting for the pest and its damage as the corn plants are emerging.

Stalk Borers

Stalk borer moths lay their eggs during late August and September, primarily on weedy vegetation in set-aside acres, and the eggs overwinter. The following spring, after the cover crop or weed growth begins to die from the burndown herbicide in no-till corn, newly hatched stalk borer larvae move to the emerging corn plants to feed. To reduce the potential for stalk borer damage, it is essential to have achieved good weed control within a field during August and

September when moths are laying eggs. Sprays of Ambush, Lorsban, Pounce, Pydrin, or Asana in the spring are effective if the treatments are applied when stalk borer egg hatch is underway.

SUMMARY

There is a greater probability for soil insect problems in corn planted in set-aside acres than in a corn-soybean-corn-soybean rotation. While it's unlikely that any single, **major** insect problem will result because of a one-year set-aside program, some fields could have a pest complex that includes cutworms, seedcorn maggots, grape colaspis, wireworms, and white grubs. One needs to consider the potential for an economic infestation of a pest complex, as well as a particular species, in planning an insect control program in corn after set-aside acres. Management considerations for soil insect control in corn after set-aside acres include the following:

1. **Preceding crops.** Legume seedings favor insects such as grape colaspis and several cutworm species, including dingy, claybacked, variegated, and black cutworms. Grass cover crops favor wireworms and white grubs.

2. **Tillage.** Depending on the cover crop, no-till could increase the potential for cutworms, armyworms, and stalk borers. No-tilling into fields that had grass or broadleaf weeds last August and September increases the likelihood of stalk borer damage. Corn planted without tillage in grass sod or fall-seeded rye is vulnerable to attack by armyworms.

3. **Scouting.** Assess insect populations by baiting for wireworms before planting and scouting for cutworms at plant emergence. Properly timed postemergence sprays are effective in controlling cutworms and stalk borers.

4. **Soil insecticides.** A preplant or planting-time treatment with a soil insecticide to prevent insect damage is not always an economical investment in fields of corn after a set-aside crop. However, there are exceptions. Match the insecticide to the specific target pest(s) based on the previous crop. The placement, rate, and effectiveness of the insecticide will vary depending on the soil insect(s) to be controlled.

5. **Planter-box seed treatment.** A diazinon + lindane seed treatment will protect the seed from attack by seedcorn maggots and wireworms. This approach, combined with scouting for cutworms, is an effective, low cost alternative.

6. **Soybeans after set-aside.** Soil insect problems are seldom economic so a soil insecticide usually isn't needed. Scout for cutworms when soybeans begin to emerge.

Reference Cited

Bigger, J.H., and H.B. Petty. 1965. Insect infestation of corn roots in Illinois. *Univ. of Ill. Agr. Exp. Sta. Bull. 704.*

Table 1. Probability Estimates of Insect Damage in Corn as Affected by Cropping Sequence

Preceding crop or cover	Wireworm	Cutworm	Seedcorn maggot	Corn rootworms	White grubs	Billbugs	Grape colaspis
Sorghum/sudan	1:100	1:50	1:20	1:100	1:500	1:200	1:500
Oats/wheat	1:100	1:50	1:50	1:25[a]	1:250	1:200	1:500
Legume	1:25	1:25	1:10	1:50	1:150	1:150	1:4
Weeds (grasses and broadleaves)	1:25	1:10[b]	1:10	1:25	1:100	1:100	1:50
Grass sod (2 or more years)	1:10	1:25	1:25	1:500	1:10	1:50	1:1,000

[a]Weeds not controlled in stubble during August and September in rootworm problem area.
[b]Late spring tillage.

Table 2. Planting-Time Insecticide Alternatives for Soil Insect Control in Corn after Set-Aside Acres

Soil insecticide	Insect, insecticide rate, and insecticide placement				
	Wireworm	Cutworm	Seedcorn maggot	White grub	Billbug
AAstar	8:band	8:band	8:band	8:band	...
Counter 15G	8:band, furrow	...	8:band, furrow	8:band, furrow	8:band, furrow
Diazinon + lindane	On seed	...	On seed	...	...
Dyfonate 20G	...	...	6:band	...	...
Furadan 15G	8:band, furrow	...	...	...	...
Lorsban 15G	16:band, 8:furrow	8:band, furrow	8:furrow	8:furrow	8:band
Mocap 15G	8:band	...	...	...	...
Pounce 1.5G	...	8:band	...	...	...
Thimet 20G	6:band	...	...	6:band	...

NOTE: In the table, numbers refer to ounces of product per 1,000 foot of row, band = 7-inch band ahead of press wheel, and furrow = directed into seed slit.

Opportunities for Herbicides with Set-Aside

E. Knake

With most farmers participating in the government's Acreage Conservation Reserve (ACR) program, we have over three million acres in set-aside in Illinois. While some herbicide manufacturers, dealers, and applicators are "crying in their beer" about lost herbicide sales, others are aggressively grasping the opportunity to promote herbicides where some of the greatest need for weed control exists--on set-aside land. But can farmers afford to buy herbicides for land on which they aren't producing a crop? With Illinois farmers reportedly receiving over a billion dollars in government payments, and perhaps netting more from land out of production than they do from equivalent acres in production, they should be willing to invest in effective, convenient, and economical weed control.

Farmers are trying several different options on set-aside land:

Sorghum-sudan. Sorghum-sudan can be seeded after the planting rush for corn and soybeans. It can make rapid, vigorous growth to compete well with weeds and seed cost is reasonable. However, some farmers have been surprised by volunteer plants the next year, particularly in soybeans. Mowing or plowing the dense growth may be somewhat of a challenge. Because the planting is late and growth so dense, there usually isn't much need for herbicides to control weeds.

Winter wheat seeded in the spring. When seeded in the spring and not vernalized by the cold of winter, winter wheat produces little if any grain. Therefore, mowing should not be needed to prevent grain production. However, winter wheat can provide dense growth and compete well to help control weeds. There are nearly twice as many pounds in a bushel of wheat as there are in oats, and more seed. This can be a relatively low cost and practical procedure but caution should be taken in wheat-producing areas, because the wheat on set-aside may harbor certain insects and diseases that may invade production fields.

Oats. Many farmers have seeded oats on set-aside land. If a good job of seeding is done, oats may help control weeds initially. But as oats mature or are clipped, weeds like foxtail can proliferate and produce considerable seed to cause problems in future years. An increasing number of farmers have let their oats on set-aside mature and then disked the field. This can help to control weeds and can help cover the oat seed to encourage germination. With adequate rainfall, a dense second growth of oats can compete rather well with weeds and form a protective cover of dead oat mulch during the winter. In the spring, no-till corn or soybeans in the oat mulch can be considered.

Legumes. Such legumes as clover and alfalfa can provide one of the best covers for set-aside. While the seed may be more expensive than for some of the other options, the stand might be left several years, thus saving the cost of seedbed preparation and seed (once the legume is established). In addition, clover or alfalfa can improve soil structure, add nitrogen, and provide a good protective cover for the soil and for wildlife. Once well-established, a good stand of clover or alfalfa can aid considerably in controlling weeds.

Herbicide opportunities. Where the main growth is weeds, herbicides can be more effective, convenient, and economical than repeated mowing. Where oats are clipped before maturing, weeds generally proliferate rapidly. Gramoxone, relatively low rates of Roundup, Dowpon, Poast, Fusilade, 2,4-D, and Banvel are all considerations.

For oats and wheat, 2,4-D or Banvel can help to control both annual and perennial broadleaf weeds. If needed, Hoelon can help to control annual grass in wheat.

In the past, Illinois farmers have not used much herbicide for legumes. Most industry representatives and dealers have been tuned in primarily to corn and soybeans. However, there can be significant benefits from herbicides for establishing legumes. Treflan has been cleared for use on legumes on set-aside land and can provide very good control of grass and a few broadleaf weeds at very low cost. Although oats are often used as a "nurse crop" for legumes, Treflan can be about the same cost or even less. Oats often contain weed seed and new weeds have been introduced with oats on some farms. Herbicides contain no weed seed. Treflan can also be more convenient. Oats need to be purchased, hauled, and perhaps cleaned. A drill needs to be available or some other method of seeding needs to be determined. Most farmers have a spray unit and incorporation equipment. It is very convenient to simply pour the herbicide in the tank and incorporate it in the same manner as for corn or soybeans.

Treflan may cause slight injury to the legume, but this is usually not serious. Balan is somewhat similar to Treflan and can provide better crop tolerance but costs more than Treflan. Although Prowl and Sonalan are similar to Treflan, they have not been registered for this use.

Eptam costs a little more than Treflan but can provide greater legume tolerance and some help on additional weeds such as nutsedge and perhaps quackgrass and johnsongrass. Eradicane has performed in essentially the same manner as Eptam and may be more readily available at about the same cost but has not been labeled for this use.

Unfortunately, there are no herbicides available for surface application for legumes. In research trials, Prowl and Surflan have caused excessive injury to legumes when surface applied. Degree of legume tolerance with Cinch has varied. Surface application of Eradicane impregnated on dry fertilizer has shown some promise in research trials.

Another good approach is to seed the legume and let grass like foxtail provide a "nurse-crop" effect before killing the grass with a postemergence herbicide. Poast and Fusilade are both cleared for use on set-aside, and Poast is cleared for use on alfalfa for livestock. For control of broadleaf weeds, 2,4-DB can be used.

There are several good herbicides available to aid in establishing legumes. They can be quite effective in controlling weeds to more quickly establish high quality, high yielding hay and pasture. They also can be quite effective, convenient, and economical for set-aside land. As with most new practices, experience and a change in attitude are major stepping stones to greater adoption. Here is a new opportunity for those willing to accept the challenge.

However, if you don't need the business, and don't mind letting weeds go to seed on set-aside land, that could mean more business for your children and grandchildren.

Illinois Animal Poison Information Center: Domestic Animals and Agricultural Pesticides

V. Beasley and H. Trammel

In 1978, the Animal Poison Control Center began operations under the leadership of Dr. William Buck with the help of three graduate students. The name was eventually changed to the National Animal Poison Control Center because, even though Illinois consistently ranked highest among states in total number of calls, the majority of calls were coming from beyond Illinois. In the latter part of 1986, the name was again modified to the Illinois Animal Poison Information Center, Headquarters of the National Animal Poison Information Network (NAPINet), to reflect the fact that other centers were beginning to function in conjunction with the Illinois Center and the methods of the Illinois Center were being shared.

The Center has accepted an increasing number of calls over the past several years, with 21,900 calls received in 1986, a 54.7 percent increase over 1985 (Figure 1).

Since 1978, data collection methods have been modified and improved at least once a year. Since 1983, information on each call has been entered on computer to permit assessment of the importance of various toxicants. At this time, pertinent facts are initially recorded on the NAPINet Vet Tox Case Record form and a major portion of the information is then transferred to a Sequent computer.

Computer entries include information on the caller, the animal(s), the toxicant(s), and the assessment of the case. The **caller data base** includes: name, address, telephone number, and category of the caller (owner, DVM, veterinary technician, human poison control center, or other). The **recorded animal data** includes: species, age(s), sex(es), weight(s), breed(s), as well as the numbers at risk, affected, treated or dead at the time of the call, and the clinical signs or lesions observed (based on an extensive check-off list that is scored from mild to severe). The **toxicant information** includes: the class of toxicant (based on another check-off), specific information including trade name of product or common name of poisonous plant or venomous animal, manufacturer of product (these are generally held in computerized files that are not accessible to outside parties), and the generic constituents of the trade product or generic name of the poisonous plant, venomous animal, mycotoxin, etc.

Additional data entered on computer involves characterization of the circumstances of exposure and an indication of the Center's confidence in the data obtained. The process begins based on a series of check-offs including: 1) the **intent** of the person responsible for exposure (appropriate use, inappropriate use, malicious, accident, none, unknown); 2) the **role** of the **person responsible** for exposure (owner, DVM, PCO, government agency, company, none, unknown); 3) the **assurance that exposure occurred** (observed, evidence, suspected, possible, no exposure, unknown); 4) the **assurance of the amount of toxicant exposure**; 5) the **route of exposure** (dermal, ingestion, inhalation, injection, ocular, none, unknown); and, 6) the **location of exposure** (home, yard or garden, field or pasture, enclosure such as a barn, etc., water, garage, veterinary clinic, no exposure, unknown).

The next set of computer entries reflects the assessment criteria for the call. Included are the degree to which: 1) the **amount of exposure** is consistent with the signs observed; 2) the **time of onset and persistence of clinical effects** are consistent with the toxicant exposure; and, 3) the **clinical signs (and lesions)** in the exposed animals are consistent with all the factors involved in the case. Each of these three criteria are scored on a check-off basis as follows: totally, generally, somewhat, poorly, not, unexpected (clinical effects are not expected), unknown, or no exposure.

Finally, each call receives an overall assessment from one of the following: toxicosis (everything fits); suspected toxicosis (everything fits but some information missing or less certain); doubtful (clinical signs present but not believed to be attributable to the toxicant in question); exposure (one or more animals exposed but no clinical signs); information (usually a question pertaining to a toxicant with no exposure involved); other (another problem--usually not toxicant related); residue problem (concern regarding contamination of animal food products--usually meat, milk, or eggs).

FINDINGS IN 1986

Roughly 45 percent of the calls in 1986 were from either veterinarians or veterinary technicians, with an additional 42 percent coming from animal owners. The greatest number of calls continues to involve canines, but most of these involve only one to a few dogs at a time. By contrast, fewer calls are received regarding food animals, but, because of the number of poultry and livestock involved in production units, the total number of animals at risk is greatest for these groups.

Figure 2 compares the number of calls with the number of animals at risk. The number of calls is represented by each bar and the number of animals at risk is represented by the line graph. Note that a dual "Y" axis is used in Figure 2. Table 1 shows the number of animals involved per call.

The assignment of the source of the agent is based on the last person in the distribution chain. By far, the most commonly involved person is the owner, with almost 16,000 calls, although pest control operators were involved in 327 calls and companies in another 212. If a chemical vendor sells a compound to an owner and the owner distributes it on his or her property, then the owner is listed as the source (Figure 3).

In 1986, the oral route of exposure accounted for almost 16,000 of the calls, but dermal exposure and combined routes of exposure were also important. When the overall assessments of toxicosis and suspected toxicosis were combined, over 30 percent of the calls were believed to involve adverse effects attributable to the toxicant in question (Figure 4). The relative number of residue calls was rather low, but these sometimes represent extremely large economic losses.

The location of exposure was greatest in the home because of the large number of small animal calls. Nevertheless, yards, fields, enclosures, and other areas were also important. When areas outside of the home or garage were involved (such as yards, fields, enclosures), the number of "exposure" calls was lower and the number of "suspected toxicoses" and "doubtfuls" was higher (Figure 5). This is due to less monitoring of outdoor animals versus indoor animals, and results in a lower percentage of cases in which exposure is detected before outdoor animals show signs of being poisoned.

Comparisons of the overall assessments made with the source of the agent revealed that when pest control operators were involved, many calls were assessed as exposures. This is a function of the heavy involvement of anticoagulant rodenticides, whose long delay before onset permits time for therapeutic intervention. When companies were involved, the degree of assurance of the circumstances of exposure was often reduced and toxicants less thoroughly characterized in animals were often involved, resulting in an increased number of suspected toxicoses and a lesser number of toxicosis calls (Figure 6).

Prior to 1987, a summary of each call was written by the veterinarian handling the call and then entered on computer. Although very helpful, the arrangement and emphasis of facts varied among individuals. Because we were collecting the pertinent information anyway, we developed the ability to computer-generate the call summaries. At first glance these seem somewhat awkward. Within minutes, however, it becomes easy for the reader to understand the information presented.

The following are representative computer-generated summaries of cases encountered in 1987. These reflect the nature of some of the more common pesticide toxicoses in birds and livestock exposed in the field. The editorial comments were added at the time of this writing and are not a part of the medical records.

1. species AVI

   summary: SUSPECTED TOXICOSIS in PIGEONS (40 AT RISK, 20 AFFECTED, 0 TREATED, 20 DEAD) UNK AGE, UNK WT, SEX UNK, showing (DIARRHEA, ATAXIA/INCOORDINAT, DEATH) at (FEW HRS onset after OBSERVED INNAPPROPRIATE COMBO ROUTE of exposure by OWNER in ENCLOSURE with UNKN AMT (UNK ASSURE) of **DIAZINON** which is consistent with: Time--GENERALLY; Amount--UNKNOWN, signs--GENERALLY. Called back 7/19 to tell toxicologist thanks, and that his pigeons are doing great.

Comment: Granular diazinon preparations are highly toxic to waterfowl and numerous other species of birds. They should not be used in locations where significant numbers of birds are present.

2. species AVI

   summary: SUSPECTED TOXICOSIS IN DUCKS (9,000 AT RISK, 0 AFFECTED, 0 TREATED, 400 DEAD) (UNK AGE, 1.2 KG, SEX UNK) AND UNK BREED, showing (WEAKNESS, ATAXIA/INCOORDINAT, DEATH) at UNK onset after SUSPECTED ACCIDENTAL ORAL exposure by UNK SOURCE in ENCLOSURE with UNK AMNT (UNK ASSURE) of **MALATHION** which is consistent with: Time--UNKNOWN; Amount--UNKNOWN; Signs--SOMEWHAT. POSSIBLE LAB CASE.

Comment: Specimens are often requested during animal poison information center conversations in order to confirm an accurate diagnosis.

3. species BOV

   summary: SUSPECTED TOXICOSIS in ANGUS CATTLE (40 AT RISK, 6 AFFECTED, 0 TREATED, 5 DEAD) (1 YR, 1000 LB, BOTH SEXES) showing (DIARRHEA, SALIVATION INCREASE, TREMORS, DYSPNEA, DEATH, RECUMBENT) at $\leq$ 2 HR onset after EVIDENCE

ACCIDENTAL ORAL exposure by OWNER in FIELD/PASTURE with UNK AMT (UNK ASSURE) of **CARBOFURAN** which is consistent with: Time--GENERALLY; Amount--UNKNOWN; Signs--GENERALLY. Also DOUBTFUL TOXICOSIS at ≤ HR onset after EVIDENCE ACCIDENTAL ORAL exposure by OWNER in FIELD/PASTURE with UNK AMT (UNK ASSURE) of **BORON** which is consistent with: Time--POORLY; Amount--UNKNOWN; Signs--POORLY.

Comment: Often, more than one agent is involved. Our overall assessments are now linked to the toxicant in question. Thus, as with the preceding call, we can indicate in our computerized files that **CARBOFURAN** was the likely source of the problem, but the exposure to **BORON** was probably incidental.

4. species BOV

summary: SUSPECTED TOXICOSIS in HOLSTEIN (50 AT RISK, 6 AFFECTED, 0 TREATED, 0 DEAD) (UNK AGE, UNK WT, SEX UNK) showing (DIARRHEA, SALIVATION INCREASE, ATAXIA/INCOORDINAT, MIOSIS) at ≤ 24 HR onset after EVIDENCE ACCIDENTAL ORAL exposure by OWNER in YARD/GARDEN with ≤ 10 LB (EVIDENCE) of **CYANAZINE** which is consistent with: Time--SOMEWHAT, Amount--SOMEWHAT; Signs--SOMEWHAT.

Comment: Spills of concentrated materials are often hazardous even with compounds of moderate toxicity.

5. species BOV

summary: TOXICOSIS in CROSSBRED BOVINE (1000 AT RISK, 100 AFFECTED, 0 TREATED, 75 DEAD) (1 YR, UNK WT, SEX UNK) showing (DIARRHEA, SALIVATION INCREASE, DEPRESSED, TREMOR, ANOREXIA, DEATH, GRUNTING) at UNK onset after UNK ASSURE of UNK INTENT, UNK ROUTE of exposure by UNK SOURCE in ENCLOSURE with UNK AMNT (EVIDENCE) of **TERBUFOS** which is consistent with: Time--UNKNOWN, Amount--UNKNOWN, Signs--TOTALLY. FIELD INVEST ON 5/8. FOLLOW-UP CALLS 5/7 FROM VET and 5/12 FROM REPORTER. CALL-BACK FROM OWNER 5/28 FOR CLARIFICATION ON FEEDING PROCEDURES.

Comment: Major incidents of death losses are often related to compounds of high toxicity that are used in concentrated forms, especially corn rootworm insecticides. Terbufos, carbofuran, phorate, and chlorpyrifos, and other compounds are most often involved. Careless use of these compounds with spillage, or contamination of vehicles that are subsequently used to transport feeds are among the more common sources of exposure.

6. species BOV

summary: TOXICOSIS in CROSSBRED BEEF CATTLE (100 AT RISK, 12 AFFECTED, 0 TREATED, 0 DEAD) (UNK AGE, 1000 LB, SEX UNK) showing (SALIVATION INCREASE, ATAXIA/INCOORDINAT) at 11-12 HR onset after OBSERVED ACCIDENTAL ORAL exposure by OWNER in FIELD/PASTURE with UNK AMNT (OBSERVED) of **DISULFOTON** which is consistent with: Time--GENERALLY; Amount--GENERALLY; Signs--GENERALLY. INSECTICIDE WAS SPRAYED ON WHEAT. FOLLOW-UP CALL FROM ATTENDING VETERINARIAN FOR INFORMATION LATER IN DAY.

Comment: Just because a formulation is approved for a given use by the EPA, it is not necessarily safe for that use. Disulfoton has an LD_{50} of 2.6 mg/kg. Remember that LD_{50}s are conducted in laboratory animals and the influence of different species, breeds, ages, sexes, stages of development, and diets of poultry, livestock, and other domestic animals can cause marked differences in susceptibility.

OTHER CAPABILITIES OF THE SYSTEM

Various reports are possible with the Illinois Center's system. To get an idea as to which categories or individual compounds are causing the most common poisoning problems, we are able to display our calls according to class or generic and sort them by assessment. Tables 2 and 3 show the nature of the 1986 calls for cattle sorted in this fashion.

In addition, if information on a particular compound is sought, as in the case of carbofuran, additional reports can be generated, some of which are shown in Tables 4 and 5.

These tables illustrate how the computerized data can be manipulated to provide an index of the safety of given formulations when used near animals. The data can help identify particularly troublesome formulations or uses of given generic pesticides or product formulations.

HERBICIDES IN GENERAL

The majority of toxicoses or suspected toxicoses related to herbicide use are associated with the more toxic compounds such as the triazines (atrazine and prometon), the phenoxy acids (2,4-D, MCPP, and others), and benzoic acids (particularly dicamba). With these compounds, as with paraquat, poisoning is most likely when exposure to concentrates or spray solutions occurs; but in livestock, it is not often associated with exposure to modest amounts of overspray or to properly treated fields alone.

RESIDUES IN GENERAL

Occasionally, the Center receives requests for information on the time factors and practices to ensure depletion of violative residues from edible tissues or milk of animals exposed to toxicants. Individuals caring for such animals are often prevented from marketing their animals until there is evidence that the animals are free of contamination.

For many of the newer compounds, a short period of time (days) is sufficient to allow for depletion to below-violative residues. It is usually economically wise and always important (in order to ensure consumer confidence) to be certain that residues are not present before shipping animal food commodities to market. Sometimes, the residue depletion plan may have to be implemented after contacting the chemical manufacturer to obtain data from their in-house studies.

Occasionally, specimens of milk, fat, or eggs are obtained for analyses. This occurs primarily with organochlorine insecticides (aldrin, dieldrin, chlordane, heptachlor) and sometimes other halogenated compounds such as polychlorinated biphenyls (PCB's). In those cases, the specimens of fat or milkfat are analyzed and, after the residue concentrations are determined, we consult with the owner, consider the economic realities of the situation, and help to decide whether it is feasible to institute a program and timetable for depleting the residues from the contaminated animals. Subsequent analysis of fat biopsies or milkfat may be conducted. Highly contaminated or less valuable animals are sometimes killed and buried if that is more economical than restoring the animals to marketable condition or converting the animals to alternate purposes, such as the use of heifers as breeding stock.

PROBLEM FORMULATIONS

Pesticides continue to rank quite high among the agents responsible for toxicoses in animals (Figure 7).

As mentioned earlier, corn rootworm insecticides are commonly responsible for poisoning in the Midwest. One reason for this is that they are often indistinguishable from other substances on the farm such as mineral mixes. It is essential to tell clients that purchase their own chemicals to avoid repackaging pesticides in containers used for other practices and always to store pesticides in an area free from feed ingredients.

Another common problem is with methomyl containing sugar baits that commonly poison the farm dog and sometimes even livestock. Marketing a particularly hazardous product such as this can understandably cause the loss of a good client.

NEED FOR ADDITIONAL CENTERS

At this time there are only two animal poison information centers in the country--the Illinois Center and a center at the College of Veterinary Medicine at the University of Georgia. It is essential that veterinarians and animal owners have access to current knowledge so that they can effectively deal with chemical exposures of animals. With the information explosion that we are experiencing, it has become impossible for the unassisted veterinary practitioner to know how to respond to the many types of pesticide exposures involved. Improving information access through the development of the National Animal Poison Information Network will help to alleviate unwarranted concern when chemical exposure is inconsequential. Of greater importance, when toxicoses or residue problems result from chemical exposure, information developed collectively and made available through the Centers can result in the provision of appropriate recommendations for emergency therapy and the means to minimize residue-associated economic losses.

Additional information on the National Animal Poison Information Network can be obtained by calling (217)244-7732; and information on the Illinois Center can be obtained by calling (217)333-2053. If emergency information on toxicants is needed, the Illinois Center's number is (217)333-3611 and the Georgia Center's number is (404)542-6751. Until additional funding is available to handle the burgeoning number of calls, we respectfully request that our numbers are neither published nor broadcast via the media.

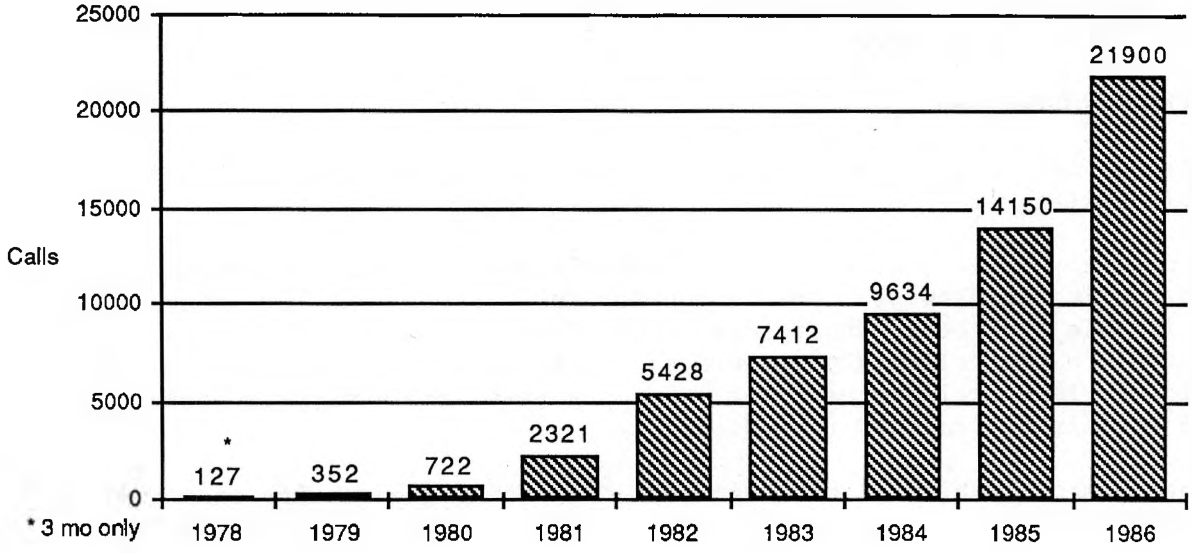

Figure 1. Total calls received by the Center, 1978-1986.

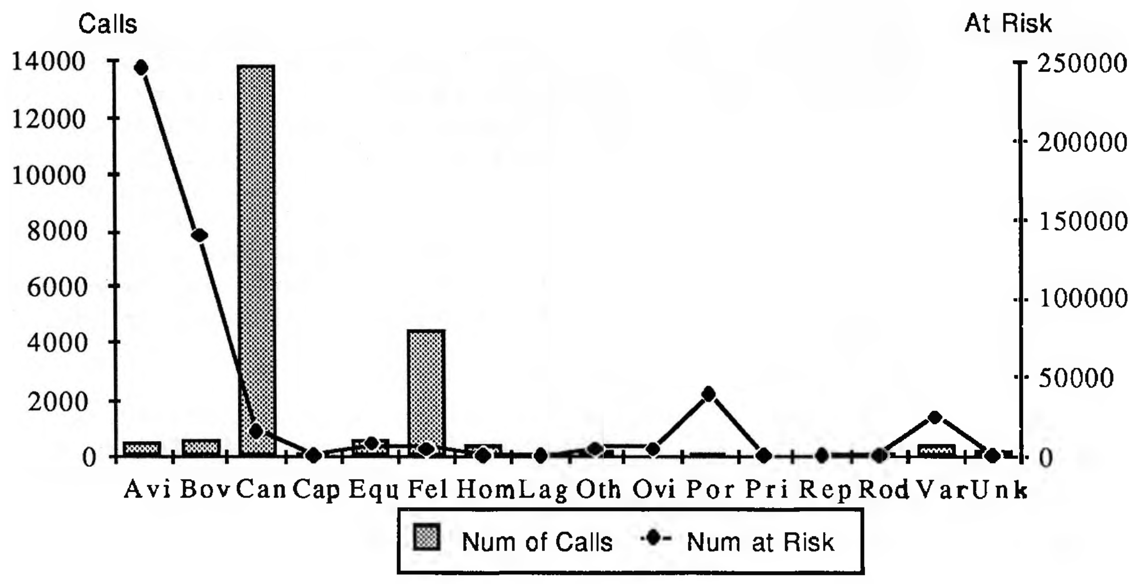

Figure 2. Number of calls versus number at risk, 1986 (note the dual "Y" axis).

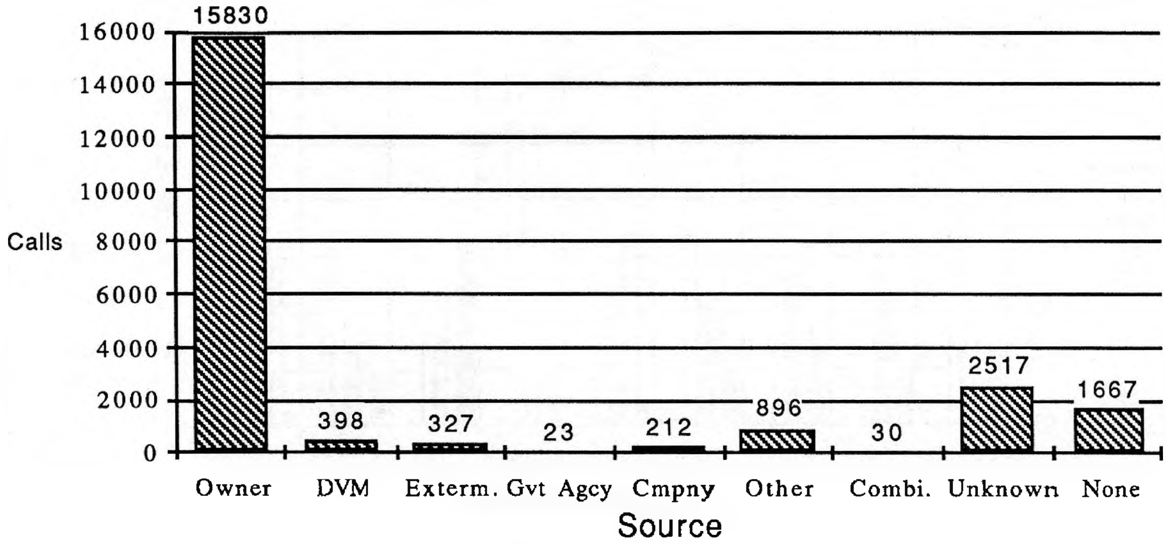

Figure 3. Source of agent for calls received, 1986.

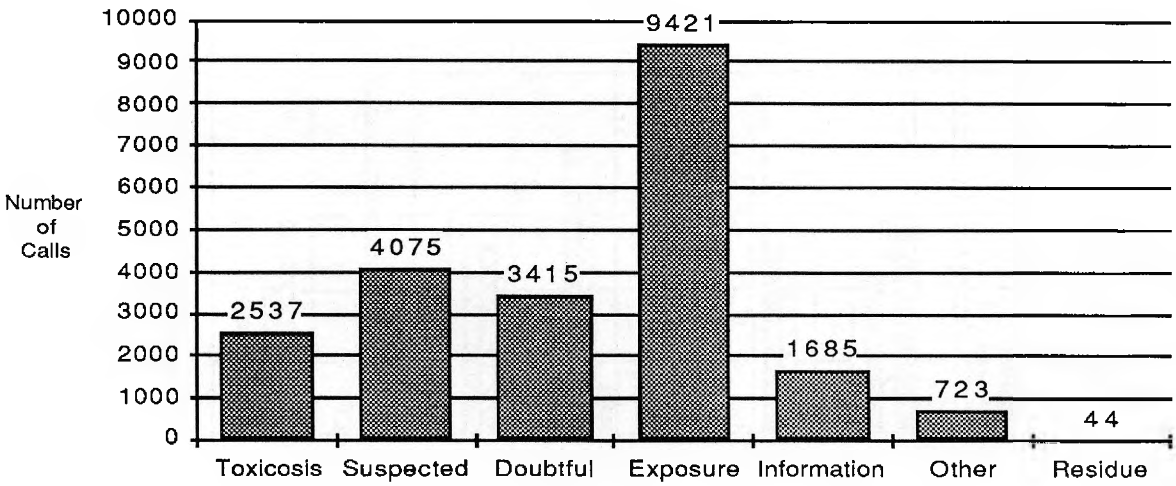

Figure 4. Assessment for calls received, 1986.

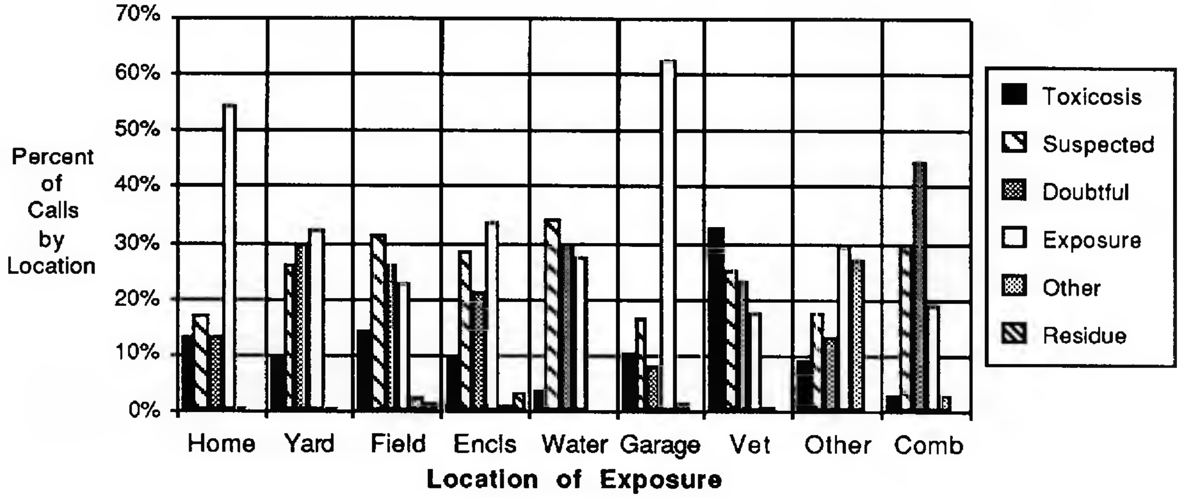

Figure 5. Comparison of assessments made and location of exposure.

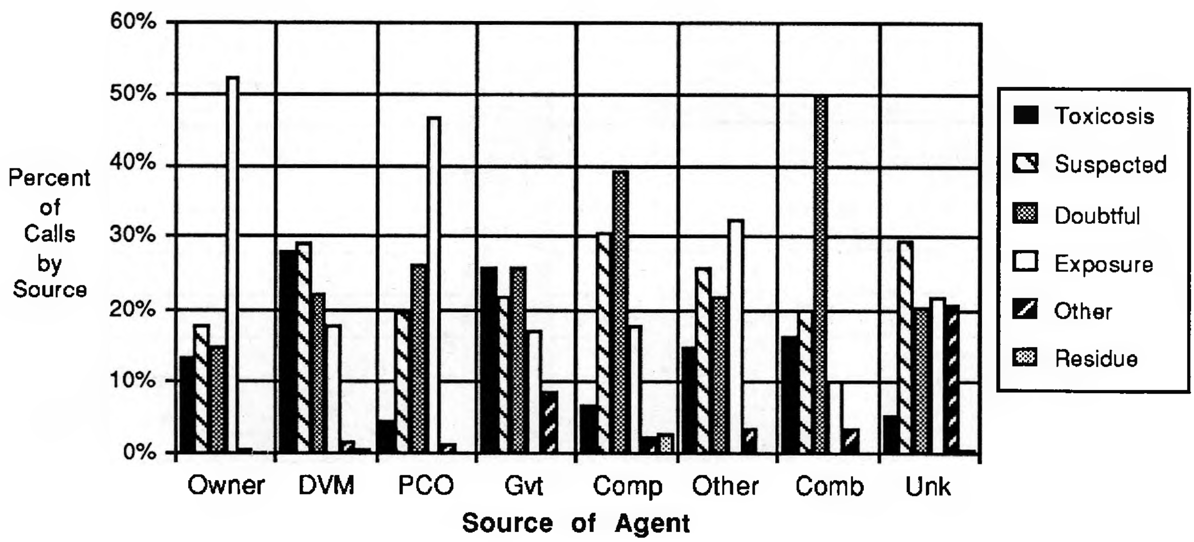

Figure 6. Comparison of assessments made and agent source.

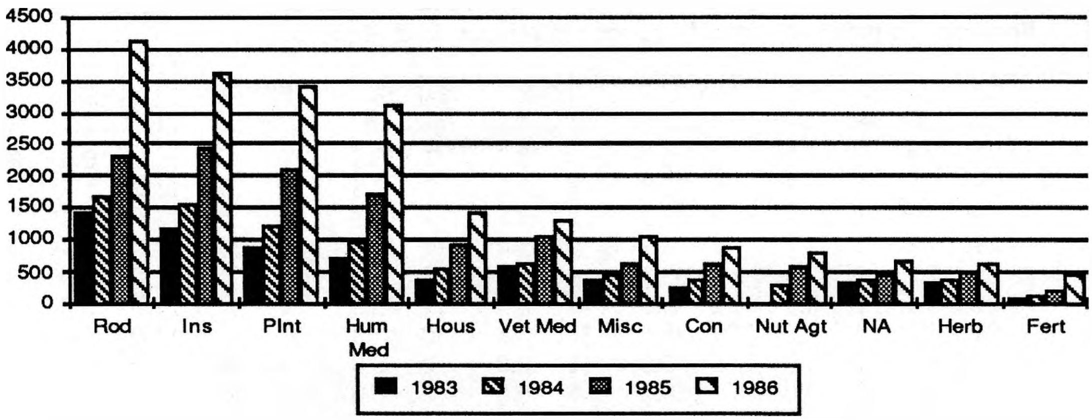

Figure 7. Comparison of top 11 classes, 1983-1986.

Table 1. Mean Number of Animals Involved per Call

Species	1984	1985	1986
Avi	57.41	204.06	445.93
Bov	50.54	137.60	228.34
Can	1.06	1.14	1.20
Cap	1.90	5.68	5.92
Equ	3.24	7.28	13.38
Fel	1.12	1.31	1.25
Hom	1.01	0.78	1.10
Lag	1.04	4.75	1.39
Other	--	--	30.88
Ovi	40.00	75.68	66.69
Porcine	106.06	279.03	274.55
Primate	1.33	1.50	2.32
Reptile	1.00	0.83	39.36
Rodent	4.76	8.11	5.22
Various	2.12	107.44	77.28
Unknown	--	0.56	0.0

Table 2. *Bovine Inquiry Distribution by Class and Reason*

CLASS	TOTAL		TOXICOSIS		SUSPECT		DOUBT		EXPOSE		INFORM		OTHER		RESIDUE	
	Num	%	Num	%	Num	%	Num	%	Num	%	Num	%	Num	%	Num	%
Avicide	3	0.4	0	0.0	2	66.7	0	0.0	1	33.3	0	0.0	0	0.0	0	0.0
Biotoxin	36	5.2	1	2.8	14	38.9	8	22.2	1	2.8	10	27.8	2	5.6	0	0.0
Combin	9	1.3	1	11.1	2	22.2	2	22.2	1	11.1	0	0.0	0	0.0	3	33.3
Constrc	23	3.3	2	8.7	2	8.7	3	13.0	7	30.4	9	39.1	0	0.0	0	0.0
Fertilizer	15	2.1	2	13.3	8	53.3	1	6.7	3	20.0	1	6.7	0	0.0	0	0.0
Fungicide	24	3.4	2	8.3	2	8.3	2	8.3	11	45.8	6	25.0	0	0.0	1	4.2
Herbicide	85	12.2	6	7.1	22	25.9	33	38.8	10	11.8	14	16.5	0	0.0	0	0.0
Hotline Info	4	0.6	0	0.0	0	0.0	0	0.0	0	0.0	4	100.0	0	0.0	0	0.0
Household	2	0.3	0	0.0	1	50.0	0	0.0	0	0.0	1	50.0	0	0.0	0	0.0
Hum Med	1	0.1	0	0.0	1	100.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Insecticide	116	16.6	24	20.7	32	27.6	12	10.3	14	12.1	22	19.0	0	0.0	12	10.3
Metal	31	4.4	2	6.5	12	38.7	6	19.4	2	6.5	8	25.8	1	3.2	0	0.0
Misc Chem	60	8.6	6	10.0	15	25.0	14	23.3	6	10.0	14	23.3	3	5.0	2	3.3
Mollusc	1	0.1	1	100.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
NA	28	4.0	2	7.1	15	53.6	6	21.4	1	3.6	0	0.0	4	14.3	0	0.0
Nutri Agt	57	8.2	5	8.8	27	47.4	9	15.8	5	8.8	6	10.5	4	7.0	1	1.8
Other	12	1.7	0	0.0	0	0.0	1	8.3	1	8.3	8	66.7	1	8.3	1	8.3
Petroleum	14	2.0	1	7.1	5	35.7	0	0.0	4	28.6	4	28.6	0	0.0	0	0.0
Plant	129	18.5	23	17.8	30	23.3	11	8.5	11	8.5	47	36.4	3	2.3	4	3.1
Rodenticide	16	2.3	0	0.0	0	0.0	2	12.5	11	68.8	2	12.5	1	6.3	0	0.0
Vet Med	33	4.7	5	15.2	8	24.2	7	21.2	1	3.0	7	21.2	1	3.0	4	12.1
TOTALS:	699	100.0	83	11.9	198	28.3	117	16.7	90	12.9	163	23.3	20	2.9	28	4.0

Table 3. *Bovine Inquiry Distribution By Top Generics and Reason*

GENERIC	TOTAL		TOXICOSIS		SUSPECT		DOUBT		EXPOSE		INFORM		OTHER		RESIDUE	
	Num	%	Num	%	Num	%	Num	%	Num	%	Num	%	Num	%	Num	%
NA	36	5.2	3	8.3	18	50.0	8	22.2	1	2.8	2	5.6	4	11.1	0	0.0
Nitrates	23	3.3	4	17.4	6	26.1	2	8.7	1	4.3	9	39.1	1	4.3	0	0.0
Monensin	21	3.0	3	14.3	8	38.1	2	9.5	3	14.3	2	9.5	2	9.5	1	4.8
Heptachlor	18	2.6	0	0.0	0	0.0	0	0.0	3	16.7	7	38.9	0	0.0	8	44.4
Atrazine	17	2.4	3	17.6	4	23.5	6	35.3	1	5.9	3	17.6	0	0.0	0	0.0
Taxus Cuspid	17	2.4	12	70.6	3	17.6	0	0.0	0	0.0	1	5.9	0	0.0	1	5.9
2,4-D	14	2.0	0	0.0	4	28.6	7	50.0	2	14.3	1	7.1	0	0.0	0	0.0
Lead	12	1.7	4	33.3	4	33.3	2	16.7	1	8.3	0	0.0	0	0.0	1	8.3
Sorghum Nos	12	1.7	2	16.7	1	8.3	0	0.0	1	8.3	8	66.7	0	0.0	0	0.0
Captan	11	1.6	0	0.0	1	9.1	1	9.1	4	36.4	3	27.3	0	0.0	2	18.2
Brodifacoum	10	1.4	0	0.0	0	0.0	1	10.0	8	80.0	1	10.0	0	0.0	0	0.0
Carbofuran	9	1.3	5	55.6	1	11.1	2	22.2	1	11.1	0	0.0	0	0.0	0	0.0
Mycotoxins N	9	1.3	0	0.0	4	44.4	1	11.1	1	11.1	2	22.2	1	11.1	0	0.0
Urea	8	1.1	1	12.5	5	62.5	1	12.5	0	0.0	0	0.0	1	12.5	0	0.0
Coumaphos	7	1.0	1	14.3	2	28.6	2	28.6	2	28.6	0	0.0	0	0.0	0	0.0
Terbufos	7	1.0	3	42.9	4	57.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Carboxin	6	0.9	1	16.7	0	0.0	0	0.0	5	83.3	0	0.0	0	0.0	0	0.0
Chlorpyrifos	6	0.9	2	33.3	0	0.0	1	16.7	1	16.7	2	33.3	0	0.0	0	0.0
Famphur	6	0.9	1	16.7	3	50.0	0	0.0	0	0.0	0	0.0	0	0.0	2	33.3
Fonofos	6	0.9	2	33.3	2	33.3	1	16.7	0	0.0	0	0.0	0	0.0	1	16.7
Levamisole	6	0.9	1	16.7	3	50.0	0	0.0	1	16.7	0	0.0	0	0.0	1	16.7
N-P-K	6	0.9	0	0.0	5	83.3	0	0.0	0	0.0	1	16.7	0	0.0	0	0.0
Solanum Nigr	6	0.9	0	0.0	0	0.0	0	0.0	0	0.0	5	83.3	0	0.0	1	16.7
Gossypium No	5	0.7	0	0.0	3	60.0	1	20.0	0	0.0	1	20.0	0	0.0	0	0.0
Info	5	0.7	0	0.0	0	0.0	0	0.0	0	0.0	5	100.0	0	0.0	0	0.0
Quercus Nos	5	0.7	0	0.0	5	100.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

Table 4. Overview for Carbofuran, 1986

Call Volume for CARBOFURAN

Total Number	Single Generic	Primary Generic	Remaining Calls
26	25	1	0

ASSESSMENT DISTRIBUTION FOR GENERIC

GENERIC	TOTAL	%	TOXI	%	SUSP	%	DOUB	%	EXPO	%	INFO	%	OTH	%	RES	%
CARBOFURAN	26	100	12	46	5	19	3	11	3	11	1	3	2	7	0	0

ASSESSMENT DISTRIBUTION FOR CLASS

CLASS	TOTAL	%	TOXI	%	SUSP	%	DOUB	%	EXPO	%	INFO	%	OTH	%	RES	%
COMBINATION	1	3	1	100	0	0	0	0	0	0	0	0	0	0	0	0
INSECTICIDE	25	96	11	44	5	20	3	12	3	12	1	4	2	8	0	0

ASSESSMENT DISTRIBUTION FOR TOT TRADE

TOT TRADE	TOTAL	%	TOXI	%	SUSP	%	DOUB	%	EXPO	%	INFO	%	OTH	%	RES	%
1	21	80	10	47	5	23	1	4	3	14	1	4	1	4	0	0
2	5	19	2	40	0	0	2	40	0	0	0	0	1	20	0	0

ASSESSMENT DISTRIBUTION FOR SPECIES

SPECIES	TOTAL	%	TOXI	%	SUSP	%	DOUB	%	EXPO	%	INFO	%	OTH	%	RES	%
AVI	1	3	1	100	0	0	0	0	0	0	0	0	0	0	0	0
BOV	9	34	5	55	1	11	2	22	1	11	0	0	0	0	0	0
CAN	10	38	6	60	4	40	0	0	0	0	0	0	0	0	0	0
EQU	3	11	0	0	0	0	0	0	1	33	1	33	1	33	0	0
FEL	1	3	0	0	0	0	1	100	0	0	0	0	0	0	0	0
POR	1	3	0	0	0	0	0	0	1	100	0	0	0	0	0	0
UNK	1	3	0	0	0	0	0	0	0	0	0	0	1	100	0	0

Table 5. Assessment Distribution for Location

LOCATE	TOTAL	%	TOXI	%	SUSP	%	DOUB	%	EXPO	%	INFO	%	OTH	%	RES	%
	ASSESSMENT DISTRIBUTION FOR LOCATE															
HOME	2	7	1	50	1	50	0	0	0	0	0	0	0	0	0	0
YARD/GARDEN	2	7	2	100	0	0	0	0	0	0	0	0	0	0	0	0
FIELD/PASTUR	11	42	4	36	3	27	2	18	2	18	0	0	0	0	0	0
ENCLOSURE	1	3	1	100	0	0	0	0	0	0	0	0	0	0	0	0
NONE	1	3	0	0	0	0	0	0	0	0	1	100	0	0	0	0
GARAGE	1	3	1	100	0	0	0	0	0	0	0	0	0	0	0	0
UNK LOCATION	6	23	2	33	1	16	1	16	1	16	0	0	1	16	0	0
OTHER LOCATE	2	7	1	50	0	0	0	0	0	0	0	0	1	50	0	0

TWENTY MOST FREQUENT SIGNS

SIGN	NUMBER	PERCENT
DEATH	10	16
SALIVATION	8	12
VOMITING	5	8
TREMOR	5	8
DIARRHEA	4	6
ADDITIONAL	4	6
DYSPNEA	3	4
TACHYCARDIA	2	3
WEAKNESS	1	1
SEIZURE	1	1
MIOSIS	1	1
HYPERTHERMIA	1	1
HYPERACTIVE	1	1
HEPATOPATHY	1	1
EDEMA	1	1
COMA	1	1
ATAXIA	1	1
ANOREXIA	1	1
PATH URIN	1	1
PATH SKELETA	1	1

New Developments Regarding Extended Diapause in Northern Corn Rootworms: Research and Survey Results

E. Levine, D. Kuhlman, K. Steffey, and H. Oloumi-Sadeghi

Western and northern corn rootworms are the most serious insect pests of corn in Illinois. Adults of both species lay the vast majority of their eggs in the soil of cornfields during August and September; they lay very few eggs in other crops. It has long been recognized that crop rotation is a very effective means of limiting damage by rootworm larvae in corn. In last year's proceedings of the Illinois Agricultural Pesticides Conference (Levine 1987), preliminary data suggested that a portion of an east central Illinois population of northern corn rootworms had the extended diapause trait, a trait allowing eggs of this species to pass two winters, rather than the normal single winter, in suspended development without hatching. This could result in larval damage to the roots of a corn crop following a rotational crop such as soybeans.

Here we present data confirming the extended diapause trait in a portion of a northern corn rootworm population in east central Illinois and preliminary results of a survey to detect the incidence of the extended diapause trait in different parts of the state. The results of a 1987 rootworm damage survey of corn following soybeans are also presented.

CONFIRMATION OF THE EXTENDED DIAPAUSE TRAIT

Eggs were obtained from adult northern corn rootworms collected at Champaign, Illinois, in August 1985. Rootworm adults were brought back to the laboratory, caged over soil placed in petri dishes (Krysan et al. 1984), and allowed to lay eggs in the soil. In late August and early September 1985, the eggs in the soil were placed in an environmental chamber simulating mean historical 4-inch soil temperatures at Champaign. Temperature was adjusted monthly. In May 1986, the eggs were removed from the soil with a sieve, counted, placed on moist filter paper in petri dishes, and returned to the chamber. Egg hatch was monitored daily. In September 1986, the remaining unhatched eggs were returned to soil in petri dishes within the chamber. In May 1987, the eggs were once again removed from the soil with a sieve, counted, and placed on moist filter paper in petri dishes, and returned to the chamber. Egg hatch was monitored daily.

Approximately 50 percent of the eggs laid by the northern corn rootworms during the summer of 1985 had neither hatched nor died by September 1986 (percentage still viable in Table 1). This suggested that these eggs were still in diapause and could require another chilling period before they would hatch. This was confirmed this past summer with the additional egg hatch. Of the 713 eggs that hatched over the two-year period, 55.1 percent hatched after one simulated winter and 44.9 percent hatched after two simulated winters. Interestingly, 24.4 percent of the eggs that passed one winter without hatching did not hatch and were apparently still viable after a second simulated winter. This suggests that diapause in the northern corn rootworm is variable and that some eggs pass through more than two winters without hatching.

STATEWIDE INCIDENCE OF EXTENDED DIAPAUSE IN NORTHERN CORN ROOTWORM POPULATIONS

Northern corn rootworm beetles were collected in August 1986 from four fields that had experienced greater than expected larval feeding in a July 1986 survey of corn rootworm damage to corn following soybeans (Kuhlman and Steffey 1987). For comparison, adults were also collected in the Champaign field that was sampled for adults in 1985. The rootworm adults were brought back to the laboratory, where they were separately caged (by field location) over soil placed in petri dishes. The beetles were allowed to lay eggs in the soil. In late August and early September 1986, the eggs in the soil were placed in an environmental chamber simulating mean historical 4-inch soil temperatures at Champaign. Temperature was adjusted monthly. In May 1987, the eggs were removed from the soil with a sieve, counted, placed on moist filter paper in petri dishes, and returned to the chamber. Egg hatch was monitored daily.

The percentage of eggs that did not hatch or die by September 1987 and that were apparently still viable ranged from 15.1 percent for eggs laid by adults collected in an Ogle County field to 54.8 percent for eggs that were laid by adults collected in a Will County field (Table 2). This suggests that these viable eggs are still in diapause and may require another chilling period before they hatch. To confirm this, these eggs are being subjected to another "winter" in the environmental chamber. It may be just coincidence that the incidence of extended diapause (presumed at this point) was lowest in northwestern Illinois; however, that portion of the state produces relatively more continuous corn than rotational corn compared with other regions of Illinois. Krysan et al. (1986) also reported finding a greater incidence of extended diapause in areas of South Dakota and Minnesota where corn is rotated annually with another crop than in areas where corn is planted without rotation. Growing corn in annual rotation with another crop provides strong selection pressure for northern corn rootworm eggs to remain in diapause for two years. Eggs that pass two winters without hatching under such a cropping pattern would have a greater chance for survival and be more likely to pass that genetic information on to their offspring. In laboratory and field studies, extended diapause has not been found in the western corn rootworm (Levine 1987; Krysan et al. 1984, 1986). Krysan et al. (1986) concluded that extended diapause is unlikely to evolve in the western species.

ROOTWORM DAMAGE SURVEY: CORN AFTER SOYBEANS

Corn rootworm damage to corn following soybeans was reported to University of Illinois entomologists and verified in a few fields in Marshall, Ogle, and DeKalb counties during July 1986. These observations of damage prompted us to conduct a random survey for rootworm damage in 300 fields of corn after soybeans in 30 counties in the northern half of Illinois in 1986. Only 2 of the 300 fields had root damage ratings that exceeded 3.0 (Table 4). These fields were located in LaSalle and Kankakee counties. We concluded, but could not confirm, that extended diapause in the northern corn rootworm population was probably the cause for the rootworm damage where corn followed soybeans.

Based on our 1986 survey, we predicted that a few scattered fields of corn after beans would have rootworm damage in 1987, most likely in east central counties where northern corn rootworm beetles have comprised about 50 percent of the rootworm population for the last four years. Our forecast was fairly accurate. We received and confirmed reports of economic rootworm damage in corn after beans in Iroquois, Kankakee, Livingston, and Ford counties. In addition, a random survey of 290 fields in 29 counties during July 1987, revealed rootworm damage in four fields in Will, Kendall, LaSalle, and McLean counties with root ratings of

3.0 or greater (Table 3). We suspect that the rootworm damage in these four fields in 1987, as well as the two fields in 1986, was the result of extended diapause in the northern corn rootworm population.

In perspective, the vast majority of the corn root systems (93.2 percent) sampled in the 290 fields had root ratings of 1 or 2, indicating that rootworm damage to corn following beans was virtually nil in 1987 (Table 3). Even though rootworm damage in corn after beans was noneconomic in 98.6 percent of the fields, the data indicate a slight increase in rootworm damage in 1987 compared with 1986 (Table 4). For example, 6.2 percent of the plants had ratings of 3.0 or greater in 1987, compared to 3.2 percent in 1986. Furthermore, there was an increase in the percentage of fields with root ratings in the range of 2.0 to 2.9, particularly in the east and northeast regions during 1987 (Table 4). The increase in rootworm damage in corn after soybeans from 1986 to 1987 was not very great, and may not be of any significance from an economic and biological standpoint. However, Extension and research entomologists will continue to monitor the situation in 1988.

Almost every year entomologists encounter some unusual insect problems that do not conform to the "norm." It should be mentioned, for the record, that University of Illinois and Natural History Survey entomologists observed moderate to severe damage caused by the western corn rootworms in several fields of corn after soybeans in an east central county in 1987. Because eggs of the western corn rootworm do not undergo extended diapause, the western corn rootworm females must have deposited their eggs in soybean fields in 1986. The logical question of course is "Why did the western corn rootworm female deposit eggs in soybeans?" We do not have an answer other than to point out that atypical events for which there are no definitive explanations occasionally occur in the insect world.

COUNTY EXTENSION ADVISER SURVEYS

During July 1987, Mike Sager and Darel Walker, Extension advisers in Woodford County, and Ned Birkey, Extension adviser in Vermilion County, conducted surveys in their counties to assess the extent of rootworm damage in corn after soybeans. The Woodford County survey showed an average root rating of 1.7 in 46 fields of corn after soybeans that were not treated with a soil insecticide and 1.8 in eight fields that were treated at planting time with a soil insecticide (Table 5). Only one of the 46 nontreated fields in Woodford County had a root rating of 3.0; the ratings for the other 45 fields ranged from 1.0 to 2.7. Rootworm damage ratings in 40 fields of corn after soybeans in Vermilion County averaged 1.25. None of the fields in the Vermilion County survey had been treated with a soil insecticide at planting.

We want to express our appreciation and thanks to Mike Sager, Darel Walker, and Ned Birkey for sharing their data for this report. Their field surveys certainly put the potential for rootworm damage in corn after soybeans in perspective for more than 100 farmers who participated in the educational program.

SITUATION FOR 1988

Should a farmer be concerned about extended diapause within the northern corn rootworm population and a potential for rootworm damage where corn follows soybeans in 1988? Although the answer is not an absolute "no," there is not sufficient research evidence to resort to a general recommendation to treat all fields of corn after beans with a soil insecticide in 1988. Because only 6 of 590 fields surveyed during 1986-87 sustained economic rootworm damage, there is little justification for widescale treatment of corn after soybeans with soil insecticides in 1988. The surveys by Sager, Walker, and Birkey in 1987 lend further support to this conclusion.

Having speculated that the likelihood of rootworm damage in corn after beans is very low, let us hasten to add that we do anticipate that a few fields will be damaged in 1988. Although it's impossible to predict where these will be, areas in east central and northeast Illinois east of Route 51, south of Route 30, and north of Route 136 are where northern corn rootworm beetle populations have been highest and where one would expect some isolated problems to occur. Rootworm damage surveys (Table 3) indicated slightly more rootworm damage in this area during 1986 and 1987.

A MANAGEMENT STRATEGY

In the few instances where corn rootworm damage in corn after soybeans has occurred in Illinois, there has been no warning of the impending problem. What can a farmer do to avoid an unexpected, unpleasant surprise?

Following are several options for growers to consider for managing the northern corn rootworm where extended diapause is suspected:

1. Growers who *confirm* rootworm damage in a corn-soybean rotation have two options:

   a) break the cycle by staying out of corn for two successive years, or,

   b)use a rootworm soil insecticide if they stay with a corn-bean-corn-bean rotation. Although current research indicates that the economic benefit of applying a soil insecticide on first-year corn is questionable, peace of mind against uncertainty may be important to some growers.

2. Consider past experience. If a grower has not been using a soil insecticide in corn after beans and soil insect problems have been absent or infrequent, he should not change plans for 1988. The probability of rootworm damage in first-year corn is very low. Scout fields for cutworm damage as corn emerges.

3. Scout fields of first-year corn in August and record the species and number of corn rootworm beetles per plant. File the information for making soil insect management decisions two years hence. Northern corn rootworm beetles would likely have to exceed two beetles per plant in a field of first-year corn to result in a sufficient number of diapausing eggs to cause larval damage to corn after beans two years later.

4. Scout fields of corn after soybeans during early- to mid-June to see if rootworm larvae are present and causing damage in fields that were not treated at planting. This option will still allow time to apply a rootworm soil insecticide at cultivation.

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Table 1. Fate of Northern Corn Rootworm Eggs Laid in Summer 1985 and Placed in an Environmental Chamber Simulating Natural Soil Temperature Conditions at the 4-inch Depth, Champaign, Illinois

	Total eggs	Hatch	Mortality	Still viable
		percentage		
May 1986	1049	---	---	---
Sept 1986	---	37.5	12.4	50.1
May 1987	472	---	---	---
Sept 1987	---	67.8	7.8	24.4

Table 2. Incidence of Extended Diapause (Presumed) in Illinois Northern Corn Rootworm Populations; Eggs Laid in the Summer of 1986

Region and county	Total number of eggs laid	Eggs still viable September 1987
		percentage
Northwest		
Ogle	332	15.1
Northeast		
Kendall	213	32.9
Will	294	54.8
Central		
Marshall	351	39.0
East		
Champaign	60	53.3

Table 3. A Survey of Corn Rootworm Larval Damage in Corn Following Soybeans in Illinois, 1987

Region and county	Number of fields surveyed	Average root rating per field	Percentage of plants categorized by root rating						Number of fields categorized by root rating (range)		
			1	2	3	4	5	6	1.0-1.9	2.0-2.9	3.0+
WEST											
Adams	10	1.44	58	40	2	0	0	0	9	1	0
Hancock	10	1.40	60	40	0	0	0	0	10	0	0
Knox	10	1.68	40	52	8	0	0	0	6	4	0
McDonough	10	1.52	52	44	4	0	0	0	9	1	0
	40	1.51	52.5	44	3.5	0	0	0	34	6	0
CENTRAL											
DeWitt	10	1.30	74	24	2	0	0	0	10	0	0
Macon	10	1.28	78	16	6	0	0	0	10	0	0
Marshall	10	2.00	26	50	22	2	0	0	5	5	0
McLean	10	2.08	22	54	18	6	0	0	5	3	2
Logan	10	1.20	80	20	0	0	0	0	10	0	0
Sangamon	10	1.14	86	14	0	0	0	0	10	0	0
Tazewell	10	1.20	80	20	0	0	0	0	10	0	0
	70	1.46	63.7	28.3	6.9	1.1	0	0	60	8	2
NORTHWEST											
Bureau	10	1.02	98	2	0	0	0	0	10	0	0
Lee	10	1.40	68	26	6	0	0	0	9	1	0
Mercer	10	1.12	88	12	0	0	0	0	10	0	0
Ogle	10	1.28	74	24	2	0	0	0	9	1	0
	40	1.21	82	16	2	0	0	0	38	2	0
NORTHEAST											
Boone	10	1.06	94	6	0	0	0	0	10	0	0
Grundy	10	1.76	30	64	6	0	0	0	6	4	0
Kane	10	1.26	76	22	2	0	0	0	9	1	0
Kendall	10	2.04	26	54	14	2	4	0	5	4	1
LaSalle	10	1.78	36	50	14	0	0	0	7	3	0
McHenry	10	1.14	86	14	0	0	0	0	10	0	0
Will	10	1.92	30	50	18	2	0	0	5	5	0
	70	1.57	54	37.1	7.7	0.6	0.6	0	52	17	1

(continued)

Table 3 (continued).

Region and county	Number of fields surveyed	Average root rating per field	Percentage of plants categorized by root rating						Number of fields categorized by root rating (range)		
			1	2	3	4	5	6	1.0-1.9	2.0-2.9	3.0+
EAST											
Champaign	10	1.64	38	60	2	0	0	0	10	0	0
Ford	10	1.80	36	50	12	2	0	0	6	4	0
Iroquois	10	1.42	60	38	2	0	0	0	9	1	0
Kankakee	10	1.46	62	30	8	0	0	0	9	1	0
Livingston	10	2.12	26	46	18	10	0	0	3	6	1
Piatt	10	1.60	46	48	6	0	0	0	9	1	0
Vermilion	10	1.38	62	38	0	0	0	0	10	0	0
	70	1.63	47.1	44.3	6.9	1.7	0	0	56	13	1
STATE TOTAL	**290**	**1.5**	**58.4**	**34.8**	**5.9**	**0.8**	**0.1**	**0**	**240**	**46**	**4**
									82.7%	**15.9%**	**1.4%**

Table 4. A Random Survey of Corn Rootworm Damage in 590 Fields of Corn After Soybeans, Illinois, 1986-87

Region	Number of fields surveyed per year 1986	1987	Average root rating per field 1986	1987	Percentage of plants with root ratings greater than 3.0 1986	1987	Number of fields with root ratings greater than 3.0 1986	1987	Number of fields with root ratings between 2.0-2.9 1986	1987
West	40	40	1.1	1.5	0	3.5	0	0	0	6
Central	70	70	1.3	1.5	2.3	8.0	0	2	4	8
Northwest	50	40	1.2	1.2	1.6	2.0	0	0	1	2
Northeast	70	70	1.5	1.6	8.9	8.9	1	1	11	17
East	70	70	1.3	1.6	3.4	8.6	1	1	5	13
Total	300	290	-	-	-	-	2	4	21	46
Average			1.3	1.5	3.2%	6.2%	0.7%	1.4%	7%	15.9%

Table 5. County Extension Adviser Surveys of Corn Rootworm Damage in Corn After Soybeans in Woodford and Vermilion Counties, 1987

County	Number of fields surveyed	Average root rating per field	Percentage of plants categorized by root ratings 1	2	3	4	5	6	Number of fields categorized by root rating (range) 1.0-1.9	2.0-2.9	3.0+
Woodford	46[1]	1.73	36	50	14	0	0	0	24	21	1
	8[2]	1.83	38	50	12	0	0	0	3	5	0
Vermilion	40[1]	1.25	77	23	0	0	0	0	37	3	0

[1]Fields were not treated with a soil insecticide at planting.
[2]Fields were treated with a soil insecticide at planting.

Can We Control Pesticide Runoff?

A. Felsot and K. Mitchell

INTRODUCTION

Most pesticides used in the Corn Belt are applied directly to the soil in the early spring to control potential weed and insect infestations. Almost all cropland is treated with a herbicide, and about half the corn acreage is treated with a soil insecticide. The coincidence of pesticide applications with cooler soil temperatures and heavy rains leads to surface runoff of pesticide-laden water and soil. Watershed areas are thus susceptible to transient fluxes of high pesticide concentrations that can be very toxic to aquatic organisms.

Baker (1985) has been assessing the dynamics of contamination of surface waters in the Lake Erie Basin, and he has reported that herbicide concentrations increase between May and July. The adverse effects of pesticide runoff can be directly seen in the number of fish kills reported each year to state conservation and environmental protection agencies (Taylor 1982, 1984). Possible risks to human health have been suggested by reports of pesticide contamination in drinking water, even after water treatment (Anonymous 1983).

Given the well-documented occurrence of pesticides in surface water and the recent discoveries of pesticide residues in groundwater, it seems that translocation of agrichemicals from target to nontarget sites is inevitable. Despite the recognized benefits of pesticides in protecting potential crop yields, pesticide contamination of nontarget systems is undesirable. Furthermore, pesticide cancellations or restrictions resulting from the United States Environmental Protection Agency's Special Review program give evidence that the public is not willing to accept the risks associated with pesticide contamination.

The dilemma of the perceived need for pesticides and the inevitable off-site contamination that follows may be resolved by the widespread implementation of practices that can reduce chemical translocation from cropland. Since toxicological risk is a function of exposure, reducing runoff and leaching of pesticides would result in lower concentrations in water supplies and thereby minimize the risk of adverse health and environmental effects.

Pesticides can be transported from cropland by both soil erosion and water runoff. Agronomic techniques that retard runoff or washoff of soil and water have been called best management practices (BMP). Conservation tillage (that is, reduced or no-tillage) may be the most promising BMP for keeping soil erosion below tolerable levels. It has been generally assumed that runoff of agricultural chemicals would be greatly reduced as conservation tillage systems are widely implemented. However, there are many kinds of tillage systems, and the utility of any one system can be fairly site- and chemical-specific (Walter et al. 1979).

Implementation of an appropriate BMP to reduce pesticide washoff depends on both the characteristics of the chemical and the watershed. By combining known variables affecting pesticide runoff in general (Wauchope 1978) with the functional relationship between the mass of translocating soil and water (and the concentration of pesticide in those media), three strategies for controlling movement of chemicals to bodies of water can be formulated (Baker and Johnson 1983): (1) reduce the volume of washoff of soil and water; (2) lower the concentration of pesticide in washoff; and, (3) retard field-to-stream delivery. Conservation tillage, contouring, closely spaced cropping, and tile drainage can greatly reduce the volume of sediment erosion and water washoff. The concentration of the chemical can be controlled by application methods and placement, application rate and timing, and chemical formulation. Terraces, grassed waterways, and filter strips can reduce the field-to-stream delivery of pesticides.

Pesticide runoff studies through 1977 have been reviewed by Wauchope (1978), and Baker and Johnson (1983) have analyzed the literature pertaining to best management practices for controlling pesticide runoff. Widespread implementation of BMPs by farmers will require an intensive study of a variety of conservation tillage systems in combination with other techniques, such as contouring, chemical placement, new formuation technology, and alternative agronomic practices (for example, use of cover crops and mulches). Pesticide runoff from cropland in Illinois has not been studied previously. Northwestern Illinois would be a prime region for studying conservation practices and pesticide runoff because of the prevalence of rolling topography.

The use of a mobile rainfall simulator on small field plots allows for the determination of pesticide runoff under a wide variety of conservation systems. Studies using simulated rainfall would represent worst-case conditions, but they would provide relatively quick answers to the question, "Can pesticide runoff be controlled?" We now report the results of our studies to assess the influence of various conservation tillage systems and contouring practices on pesticide losses from small field plots under simulated conditions of rainfall.

MATERIALS AND METHODS

During June of 1984 and 1985, experiments were conducted at the University of Illinois Northwest Illinois Agricultural Research and Demonstration Center near Monmouth, Illinois. In 1984, runoff losses of carbofuran and alachlor were monitored, and in 1985, runoff losses of terbufos and alachlor were monitored. The soil was a Tama silt loam on slopes varying between 7 and 11 percent. Tillage and orientation of plowing and planting (that is, contoured or up-and-down hill) were randomly assigned to field plots. Each field plot was divided into two adjacent subplots measuring 3 x 10 meters. Each tillage/row orientation treatment combination was replicated four times.

In 1984, moldboard-plowed plots oriented either on the contour (MBC) or up-and-down hill (MBUD) were compared to no-till plots with similar orientations. Plots were planted with corn in 1983 and soybeans in 1984. Carbofuran was applied as a granular formulation (Furadan 15G) during planting in an 18-centimeter band over the seed furrow and lightly incorporated. After planting, alachlor was sprayed over the plots without incorporation as an emulsifiable concentrate (Lasso 4E) in water. The rates of application for carbofuran and alachlor were 1.12 kilograms per hectare and 3.36 kilograms per hectare, respectively.

In 1985, five tillage systems were tested in conjunction with contouring or up-and-down hill row orientations. These were moldboard plow (MB), chisel plow (CL), ridge tillage (RD), strip tillage (ST), and no-till (NT). All plots except strip till were planted in soybean residue. The strip tillage treatment consisted of planting into a wheat cover crop that had been killed with paraquat. Seeds were planted into a 35.6-centimeters wide strip made by a Bush Hog Ro-till implement.

Within 48 hours after pesticide application, precipitation was applied from a rotating boom rainfall simulator. The simulator was positioned between two adjacent subplot treatments, and it was calibrated to deliver a nominal rainfall rate of 63 millimeters per hectare. The nozzles through which the water was delivered were calibrated so that the droplet size would simulate 85 percent of natural rainfall's impact energy.

Each subplot was surrounded by a metal barrier, and the runoff water was channeled down a flume into a pit. Combined samples of water and sediment were manually collected at regular intervals for hydrological and pesticide analyses. In the laboratory, water and sediment were separated by filtration and pesticide concentration determined in each runoff component by previously published methods (Felsot et al. 1985, 1987).

Mass loss of pesticide runoff was calculated as the product of concentration in sediment or water and the volume of each carrier corresponding to the interval of sample collection. Pesticide concentrations during time intervals between the last sample of the rising portion of the hydrograph and steady flow were interpolated from concentrations determined at those two times. Mean mass loss of pesticide runoff was statistically analyzed using the Statistical Analysis System (SAS) General Linear Means procedure and Fisher's Least Significant Difference test at the 5 percent probability level.

RESULTS AND DISCUSSION

In 1984, corn residue remaining after harvest covered greater than 85 percent of the plot surface area if plots were untilled, and less than 3 percent of the surface area if the soil was turned over with a moldboard plow (Table 1). Water runoff and soil erosion were significantly greater from MBUD plots than untilled or contoured plots. Water and soil losses from moldboard-plowed plots on the contour were not significantly different from no-till plots. Coincidentally, bulk alachlor and carbofuran losses were significantly lower from no-till and MBC plots than from MBUD plots (Table 1). Thus, contouring alone was an effective management practice for reducing runoff losses of alachlor and carbofuran.

Total percent-of-applied runoff losses of carbofuran in 1984 ranged from 1.0 percent (MBC plots) to 11.9 percent (MBUD plots). We noted that at least 10 and 100 times as much carbofuran was lost in water as in sediment from up-and-down hill and contoured plots, respectively. Caro et al. (1973) also noted that carbofuran was translocated from field plots largely by water washoff.

Loss of alachlor in runoff ranged from 0.6 percent (NTC plots) to 2.2 percent (MBUD) plots. The greatest bulk losses of alachlor occurred via water washoff. Similar observations were made by Baker et al. (1978, 1979) and Sauer and Daniel (1987).

During the summer of 1985, corn was planted into soybean residue, and five tillage systems were compared with rows on the contour or oriented up-and-down hill. No-till plots had the highest residue covers compared to other treatments but were much lower than those observed during 1984 for corn residue (Table 2). Actual rainfall amounts applied to each treatment differed because the no-till plots on the contour and both sets of strip-till plots required additional water to obtain enough runoff to make the appropriate hydrological measurements. When cumulative loss of water from contoured plots (Table 2) was normalized per millimeter of rainfall applied, water runoff decreased in the following order: MB > CL > RD > ST > NT. Up-and-down hill plots showed similar washoff relationships, except less water per millimeter of rainfall was lost from ST plots than NT plots. Significantly more water was lost from MBUD plots than from MBC plots, but significant differences between individual treatments relative to row orientation were not observed for other tillage systems.

Soil losses paralleled water losses with the MBUD plots yielding the greatest erosion (Table 2). RD, NT, and ST plots had the least amount of soil losses if plots were contoured. No significant differences were observed between row orientations for either NT or ST plots, but RD was effective in reducing soil erosion only if rows were planted on the contour.

Bulk losses of alachlor generally paralleled those for total water and soil. The greatest amounts of alachlor were lost from MBUD plots (6.3 percent of applied amount), but contouring greatly reduced these losses (1.9 percent of applied amount) (Table 3). Alachlor losses in water did not differ significantly among the other tillage systems, but losses from NTUD plots were surprisingly high (2.0 percent of applied amount) despite comparatively low volumes of water washoff. Losses of alachlor in sediment were significantly higher from MBUD plots than from the other treatments, but there were no significant differences among CL, RD, ST, or NT plots regardless of row orientation. As observed in 1984, the alachlor losses were largely via water washoff and percentages lost in soil and water combined ranged from 0.8 to 5.2 percent of the initial amount applied to the plots (Table 3).

Runoff of alachlor from ridge and chisel till systems with rows oriented up-and-down hill has also been measured by Baker et al. (1978) and Sauer and Daniel (1987) using simulated rainfall. Both researchers found that percentage of alachlor lost in these two systems could exceed that lost from conventional tillage (that is, moldboard plow). In our studies, losses of alachlor from chisel and ridge systems were always significantly lower than losses from plowed plots when rows were up-and-down hill (Table 3). In contoured plots, ridge and chisel systems yield numerically less alachlor runoff than the moldboard system, but differences were not significant.

Compared to alachlor, very little terbufos was found in runoff. However, large amounts of terbufos sulfoxide (TSO), the primary environmental metabolite of terbufos, were found in both runoff water and sediment. The large amounts of TSO in sediment were unexpected because its water solubility is even greater than alachlor. At this point, we can not be sure whether terbufos was oxidized immediately after application and during runoff, or whether TSO was formed during drying of the sediments after separation from the water phase in the laboratory. We have noted previously large amounts of TSO formation immediately after application of terbufos to field plots (Felsot et al. 1987).

Because of the large amounts of TSO recovered and the relatively high toxicity of the oxidative metabolites of terbufos, the sum of parent terbufos and its soil metabolites were considered for runoff analyses. Under up-and-down hill conditions, total terbufos losses (terbufos plus metabolites, TTS) were significantly higher in water and sediment phases of runoff from MB plots than from the other tillage treatments (Table 3). ST and NT yielded the least amounts of TTS in runoff. Under contoured conditions, CL had the highest losses of TTS but was not significantly different from MB treatments. RD was effective in reducing TTS losses compared to moldboard if contouring was used. Overall, percentage losses of TTS ranged from 0.1 (NTC) to 7.9 percent (MBUD) (Table 3). In contrast to alachlor and carbofuran, the greatest runoff losses occurred in the sediment phase. This observation was consistent with the comparatively lower water solubility and higher adsorption coefficient of terbufos compared to alachlor and carbofuran.

In summary, our experiments using small plots and simulated rainfall show that reduction of tillage, especially no-till, can significantly reduce runoff losses of alachlor, carbofuran, and terbufos. Also, contouring alone can significantly reduce pesticide runoff regardless of tillage system. Our results did not always agree with those reported by Baker et al. (1978) or Sauer and Daniel (1987) who showed that reduced-tillage systems with rows oriented up-and-down hill could produce greater losses of alachlor than conventional systems. We did observe that alachlor losses in the water phase of no-till plots oriented up-and-down hill were numerically larger than from other reduced-tillage systems. Differences between rainfall amounts, ambient soil conditions, and soil types in our study and those of Baker et al. (1979) and Sauer and Daniel (1987) could account for the relative differences in alachlor runoff among tillage types.

In conclusion, we note that no tillage system completely stopped pesticide runoff. At best, we could reduce runoff of pesticides by selecting appropriate agronomic management practices. Such practices must focus on controlling water runoff as well as soil erosion. By minimizing the amount of pesticides leaving the target sites, we can minimize the risk of adverse health and environmental effects at nontarget sites.

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Table 1. Runoff of Water, Sediment, and Pesticides from Field Plots at the Northwestern Illinois Agricultural Research and Demonstration Center Near Monmouth, June 1984

Management practice[a]	Percent residue cover	Cumulative water (mm)	Cumulative soil (kg)	Total Pesticide (mg/plot)[b] Carbofuran wat.	sed.	Alachlor wat.	sed.
MBUD	2.6	33.5	75.4	385	46.7	153	88.3
NTUD	87.2	22.2	2.8	186	0.7	74	2.4
MBC	1.4	18.1	11.1	37	0.4	82	9.7
NTC	85.6	13.4	1.3	80	0.2	64	1.0
LSD (0.05)[c]	12.1	11.1	12.6	107	18.9	49	25.4

[a]MBUD = moldboard plow, up-and-down hill
NTUD = no-till, up-and-down hill
MBC = moldboard plow, contoured
NTC = no-till, contoured
[b]Individual plots were 30 m^2. Simulated rainfall was applied within 48 hours after pesticide application.
[c]Fisher's Least Significant Difference test at P = 0.05.

Table 2. Mean Percentage Slope, Percentage Residue Cover, Total Rainfall Applied, and Cumulative Soil and Water Losses from Runoff Plots at the Northwestern Illinois Agricultural Research and Demonstration Center, June 1985

Tillage system	Percent slope	Percent residue cover	Total rainfall applied (mm)	Cumulative loss of water (mm)	soil (kg)
	Contoured plots				
Moldboard	8.1	0.9	66	22.9	37.4
Chisel	10.1	4.1	64	21.3	28.8
Ridge	9.2	11.0	74	20.7	7.1
Strip	10.5	17.1	122	22.5	8.0
No-till	8.6	36.3	92	10.9	1.9
	Up-and-Down Hill Plots				
Moldboard	9.7	1.3	68	31.1	110.1
Chisel	7.6	3.0	64	20.6	31.4
Ridge	9.7	14.8	73	23.8	36.7
Strip	9.2	38.1	106	21.4	6.2
No-till	8.4	48.6	69	16.9	12.0
LSD (0.05)[a]	1.4	10.9	16	6.8	21.6

[a]Fisher's Least Significant Difference test at P = 0.05.

Table 3. Percentage Loss of Terbufos and Alachlor in Water and Sediment Runoff from Small Plots at the Northwestern Illinois Agricultural Research and Demonstration Center, June 1985

	Percentage of applied lost from plot					
	Up-and-Down Hill			Contoured		
Tillage system	water	sediment	total	water	sediment	total
	alachlor					
Moldboard plow	5.2	1.1	6.3	1.9	0.3	2.2
Chisel	0.9	0.2	1.1	1.1	0.5	1.6
Ridge	1.2	0.2	1.4	0.8	0.1	0.9
Strip till	0.8	0.1	1.0	0.7	0.1	0.8
No-till	2.0	0.1	2.2	0.8	0.1	0.8
LSD (0.05)[a]	2.0	0.4	2.1	2.0	0.4	2.1
	terbufos + metabolites					
Moldboard plow	1.4	6.6	7.9	0.2	1.3	1.5
Chisel	0.2	1.2	1.3	0.2	3.6	3.7
Ridge	0.3	2.4	2.7	0.1	0.5	0.6
Strip till	0.0	0.2	0.2	0.2	0.5	0.7
No-till	0.1	0.4	0.5	0.1	0.0	0.1
LSD (0.05)	0.3	3.2	2.6	0.3	3.2	2.6

[a]Percentages of pesticide lost were compared statistically using Fisher's Least Significant Difference test at P = 0.05.

Bean Leaf Beetle Feeding on Pods: Effects on Soybean Yield and Seed Quality

M. Kogan, C. Helm, and D. Buchori

The bean leaf beetle, *Cerotoma trifurcata*, thrived in Illinois long before soybeans were introduced into the State. The beetles lived on native, wild legumes and also fed on cultivated garden or common beans. With the expansion of soybean cultivation in the Midwest, the bean leaf beetle found a new and plentiful resource upon which to feed and reproduce. The bean leaf beetle is one of the few species of insects associated with soybeans in the Midwest that can survive the harsh winter conditions, although overwintering survival varies substantially from year to year.

For many years, the bean leaf beetle has been considered a minor, sporadic pest of soybeans in the Midwest. It ranked fourth as a soybean pest, after the green cloverworm *(Plathypena scabra)*, grasshoppers *(Melanoplus* spp.), and spider mites *(Tetranychus urticae)*(Kogan 1982; Kogan and Helm 1983). The bean leaf beetle was notorious mainly as a foliage feeder and its populations were seldom large enough to produce damaging levels of defoliation. In the last six or seven years, however, the beetles have been noted to build up sizable populations in the latter part of the season, and these populations have been capable of producing widespread injury to green pods. It is mainly the economic impact of this type of injury that we propose to address here. This paper is a preliminary summary of our field observations and experiments conducted in Illinois since 1981.

LIFE HISTORY AND HABITS

Bean leaf beetle adults usually overwinter under dried leaves in woodlots adjacent to soybean fields. Early in the spring, as temperatures rise above 50° to 55°F, the overwintered beetles become active and begin to disperse. Not all beetles emerge from overwintering sites at the same time so there is always a chance that some of them will emerge when there is already a new soybean crop sprouting in nearby fields (Jeffords et al. 1983). We have observed, on occasions, that if beetles emerge early in the spring before soybeans emerge, they may feed and survive for a while on stinging nettle, wood nettle, and *Eupatorium* (Helm et al. 1983). They may also feed on alfalfa, but females seldom, if ever, oviposit in this forage legume.

If overwintered adults find a soybean field, even when the plants are at the hook stage, they immediately colonize that field. They feed on the epicotyls and on the cotyledons and may cause some stand thinning if the infestation is large. The females proceed to oviposit at the base of the plants, just below the soil surface.

Young larvae feed on root hairs and then on nodules as the nodules become well developed within a month after plant emergence. They undergo two molts before becoming a pupa inside earthen pupal cells. The first generation in Illinois is completed in about 50 days.

Adults begin to emerge in the latter part of July or early August. However, if early season conditions are favorable for soybean development, as they were in 1987, both soybean and bean leaf beetle development may be accelerated. Thus, in 1987, first-generation beetles could be found in some fields in central Illinois as early as the first week in July. These new adults feed on foliage and they seldom constitute a problem, because this is a period of intensive vegetative growth. Plants are tolerant of high levels of defoliation and populations are seldom large enough to exceed economic injury levels. These beetles oviposit again near soybean plants about 2 inches below ground level.

A second generation develops and new adults emerge in the latter part of August or early September, depending on the prevailing temperatures. Our predictive model indicates that under unusually favorable environmental conditions (that is, consistently high daily temperatures; adequate moisture levels, but not excess water in soils; and early planting of soybeans), there may be a third generation of beetles in a year. However, this has not been confirmed by adequate field observations. In Illinois, it seems that there are two complete generations per year (Figure 1). In Minnesota, there is only one generation per year (Loughren and Ragsdale 1986), whereas, in the Gulf Coast States, there may be three to four generations per year (Kogan et al. 1980). Second generation adults disperse to overwintering quarters when soybean plants reach harvest maturity (Jeffords et al. 1983).

NATURE OF DAMAGE

Bean leaf beetles are capable of injuring soybeans in a variety of ways. Overwintered adults that colonize soybean seedlings may feed on cotyledons, unifoliate leaves, or may actually cut germinating seeds at the hook (Figure 2). In some instances, if beetle populations are sufficiently high and cotyledon feeding or plant cutting is severe, replanting may be necessary. Ordinarily though, vigorously developing soybean stands are able to outgrow this damage as the colonizing population of beetles is fairly short-lived.

Larvae of beetles of the first and second generation feed below ground on roots and nodules. Little is known about the effects of this type of feeding. It is generally assumed that soybeans growing under normal conditions will not suffer an economic reduction in yield, even with substantial levels of nodule destruction. Clearly, this is an area of much needed research, but attempts to verify some of our assumptions have proven very difficult.

First- and second-generation adults feed mostly on soybean foliage. First-generation adults ordinarily occur in midseason when soybeans are growing rapidly; defoliation produced by adult beetles at this time is quickly compensated by new growth. Adults at this time seldom cause major concern as they rarely exceed the economic injury level.

Besides their direct effect as foliage feeders, these beetles may affect yields as they transmit the causal agent of the bean pod mottle virus disease. This disease is a serious problem in Louisiana and it has been detected in southern Illinois (Milbrath et al. 1975).

On the other hand, second-generation adults may not be content with the quality of foliage available to them late in the season when their populations peak. During the past seven years, we have seen a marked increase in pod feeding by adults of this second generation. Beetles may occasionally penetrate the pod wall completely and feed directly on the green seeds. This type of damage, however, is relatively rare compared to the scarring of the external pod tissues so commonly seen in recent years (Figure 3). Although the injury itself may appear to be relatively minor (and in some cases it may actually be of no consequence), this destruction of the protective pod wall may result in varying degrees of damage to the underlying seed.

EFFECT OF POD INJURY

We are currently attempting to quantify the effects of bean leaf beetle pod feeding on seed yield and quality to better define thresholds for this type of feeding. Seeds beneath beetle feeding scars may be shriveled, wrinkled, spotted, or moldy, or they may show no damage at all (Figure 3). Cooperative efforts with University of Illinois plant pathologists have identified nine species of fungi in association with bean leaf beetle damaged pods and seeds (Shortt et al. 1982). Surveys have shown a higher percentage rate of infection by these fungi in damaged pods than in undamaged pods from the same fields.

Although beetle injury is not required for any of these fungi to infect soybean seeds, data suggest that beetle feeding may be increasing the infectivity of these fungal pathogens into wound sites, thus compounding the effect of the feeding injury itself. Further, high levels of pod injury were associated with a loss in seed germinability; however, there was considerable variation among the cultivars tested.

Detailed examinations of damaged plants this past season showed a definite stratification of feeding preference. Pod injury was concentrated mostly in the upper one-third of the plant; that is, both a higher number and higher percentage of damaged pods were found at this level (Table 1). Damage on a percentage basis was fairly evenly distributed in the lower two-thirds of the plants we examined. This stratified injury must be taken into consideration when sampling for estimates of pod feeding to make a control decision. Levels of pod injury will easily be overestimated if sampling is concentrated on these upper pods.

The effects that bean leaf beetle pod feeding may have on soybean seed quality and weight are summarized in Table 2. Pods gathered from the small sample of plants used to develop Table 1 were characterized as either damaged or undamaged pods within their respective strata. Pods were hand-threshed and the seeds were assigned to the classes described in Table 2, counted, and weighed. Mean weight per seed from damaged pods taken from the upper one-third of the plant was significantly lower (at least 10 percent lower) in all three classes than the mean weight per seed from undamaged pods in the same stratum. This reflects the nearly 70 percent level of pod injury that we observed in that stratum (Table 1). In fact for nearly every seed class, the average weight of seeds from damaged pods in every stratum was less than that of seeds from undamaged pods in the same stratum.

Seed quality in the most heavily injured strata was also lowered. Only 56 percent of the seeds from damaged pods in the upper one-third of the plant were placed in Seed Class 1, while 25 percent and 19 percent fell into Classes 2 and 3, respectively. This is in contrast to 68 percent of the seeds from undamaged pods assigned to Seed Class 1. While this is a very small sample from a single field with an overall level of pod feeding greater than 30 percent, it illustrates the complexity of evaluating the effects of this type of injury and the potential seriousness of the problem.

Our experience with the effect of pod injury throughout central Illinois has not shown clear correlations between beetle numbers and observed levels of pod feeding. Similar population levels do not always produce the same percentage pod injury; we do not necessarily find the highest levels of pod injury in fields with the highest beetle counts. Further complicating the problem is the observation that similar levels of pod injury do not always result in similar levels of seed damage. In fact, we have often collected a great amount of damaged seed from fields with only half the level of pod feeding of a neighboring field. It seems that the time of beetle feeding during pod development and weather conditions, mainly rainfall, after pod injury occurs may explain some of this variability.

In conclusion, several factors influence both the phenology of beetle populations and crop development to produce the levels of pod feeding we have seen throughout the 1980s. These factors need to be better understood. Once beetles begin to switch their feeding from foliage to pods, another set of variables may affect losses in seed weight, seed quality, and seed germinability in injured pods. Among these variables of importance may be: (1) the level of loss in integrity of the pod wall (both number and depth of lesions); (2) stage of seed development at the time of attack; (3) environmental conditions at the time of attack and after pod injury; (4) the presence of fungal pathogens in a specific field: and, (5) possible resistance of seed to injury by this fungal complex. Work is continuing to better understand the relationship among all of the factors in order to establish more well-defined thresholds for this type of feeding by the bean leaf beetle.

Although it is premature to establish economic injury levels for bean leaf beetle injury to pods, some assumptions can be made based on data from Tables 1 and 2 and from field observations. We are currently analyzing these data to establish some preliminary working economic injury levels. Our current recommendations are based on observational, not experimental, data, and they may be conservative (Table 3). It is apparent, however, that fields in seed production will be particulary sensitive to this type of injury. Future research will have to assess this factor, as well as the impact of pod injury on general production fields.

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*Table 1. Stratification of Bean Leaf Beetle Pod Feeding**

Stratum of plant	Total number of pods	Number of injured pods	Percent pod injury
Upper third	130	90	69.2
Middle third	277	41	14.8
Lower third	49	10	20.4
Total	456	141	30.9

*Data from ten plants.

Table 3. Decision Chart for Bean Leaf Beetle Control at Stage of Seed Maturation Through Harvest Maturity

Pod injury	Number of bean leaf beetles per plant: Less than 2	2 to 5	More than 5
Less than 8 percent	Discontinue sampling.	Sample again in 5 days.	Spray (preventive if pods still green).
8 to 12 percent	Sample again in 5 days.	Spray if pods still green or beginning to yellow.	Spray if pods beginning to yellow.
More than 12 percent	Spray if pods still yellow and beetles are present.	Spray unless pods completely dry.	Spray unless pods completely dry.

Table 2. ***Bean Leaf Beetle Pod Feeding: Effect on Seed Quality and Seed Weight****

	Undamaged pods						Damaged Pods					
	Seed Class 1[a]		Seed Class 2[a]		Seed Class 3[a]		Seed Class 1[a]		Seed Class 2[a]		Seed Class 3[a]	
Plant stratum	No. of seeds	Weight (grams)[b]	No. of seeds	Weight (grams)[b]	No. of seeds	Weight (grams)[b]	No. of seeds	Weight (grams)[b]	No. of seeds	Weight (grams)[b]	No. of seeds	Weight (grams)[b]
Upper third	73	12.54 (17.18)	17	2.37 (13.65)	18	0.44 (2.28)	125	19.38 (15.50)	55	6.43 (11.69)	43	0.73 (1.67)
Middle third	284	44.65 (15.72)	167	23.91 (14.32)	61	1.77 (2.90)	56	8.65 (15.45)	34	4.42 (13.00)	19	0.51 (2.68)
Lower third	58	8.70 (15.00)	40	5.03 (12.58)	4	0.21 (5.25)	14	2.21 (15.79)	7	0.66 (9.43)	6	0.30 (5.00)

*Data from ten plants.

[a]Seed class 1 = Normal seed.
Seed class 2 = Seed with cracked or rough seed coat, discolored, stained, or mottled.
Seed class 3 = Immature, flattened, and moldy.

[b]Number with no parentheses is the total weight for the sample. Number in parentheses is the projected mean weight of 100 seeds of that class.

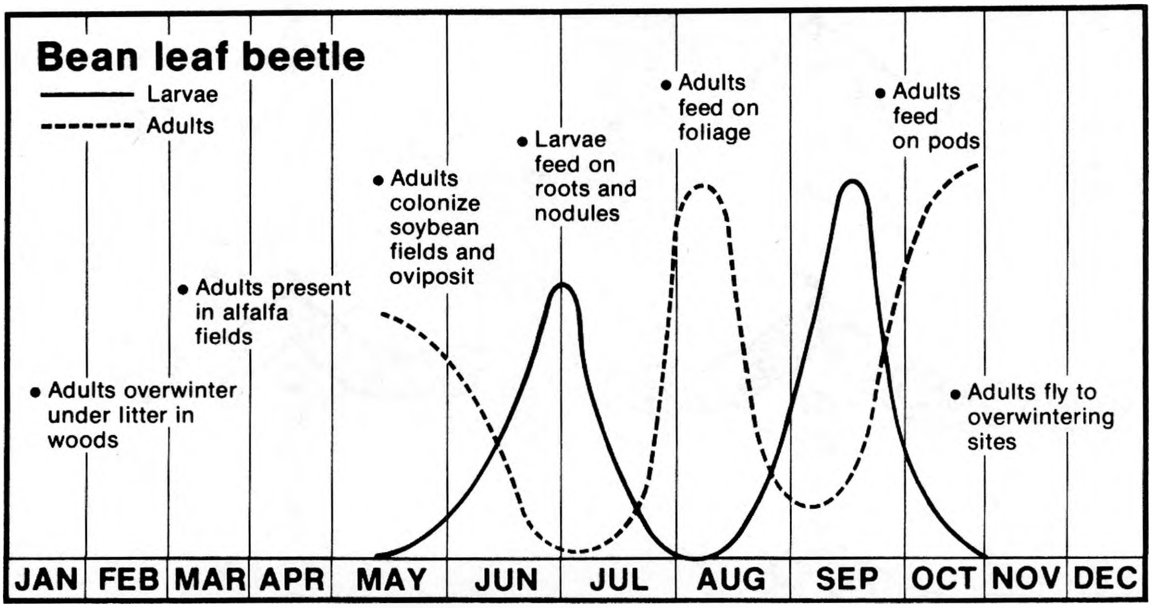

Figure 1. Phenology of the bean leaf beetle in Illinois.

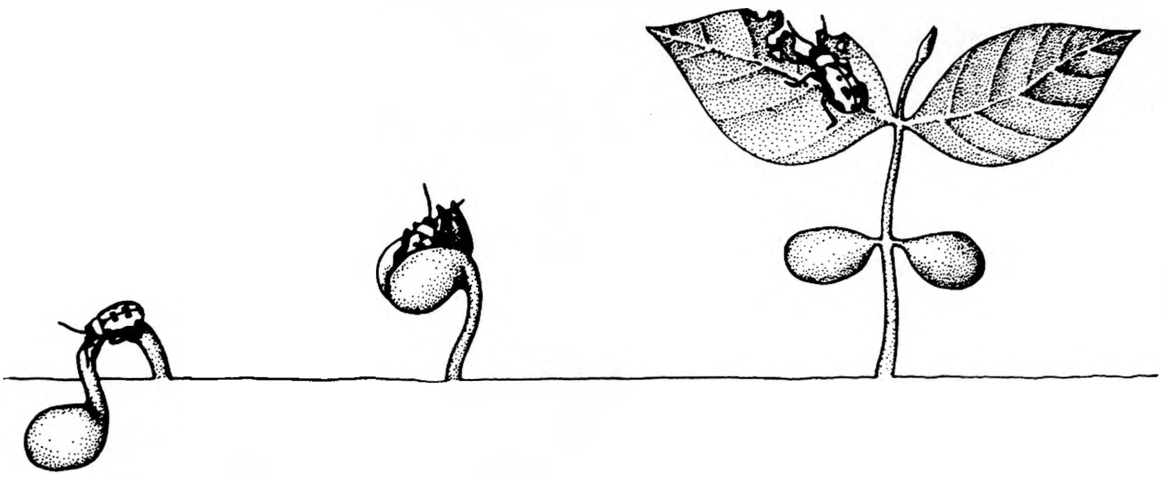

Figure 2. Bean leaf beetle feeding on soybeans early in the season. (LEFT) Feeding on the hook before seed emergence may cause rupture of the epicotyl at the point of injury. (CENTER) Feeding on cotyledons may reduce overall plant vigor. (RIGHT) Feeding on the unifoliolate leaf is usually compensated by later growth.

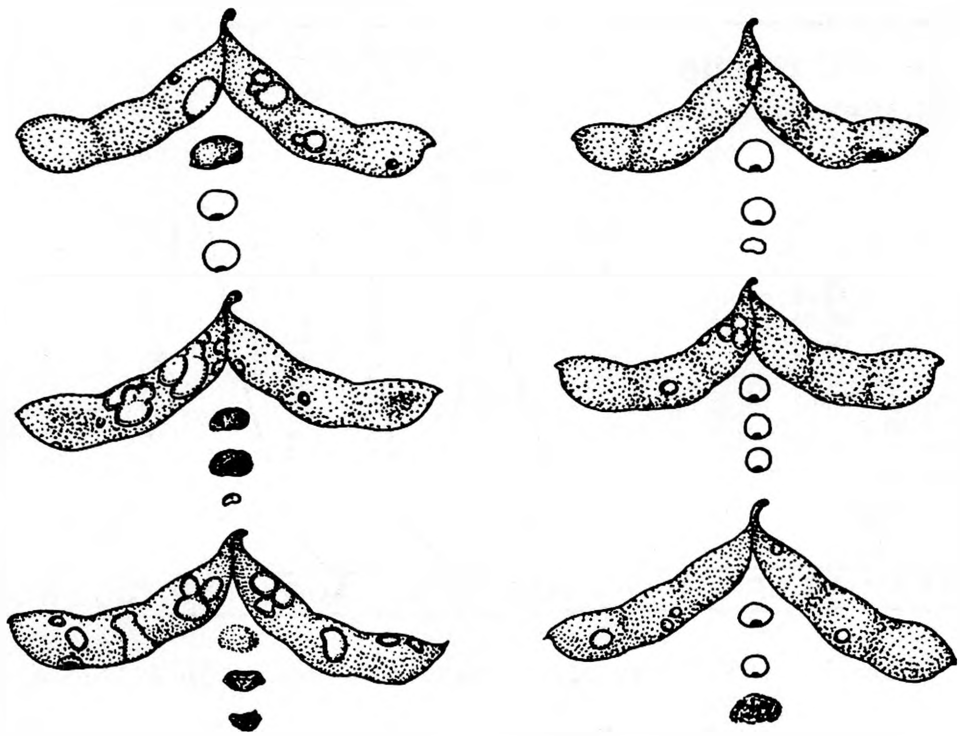

Figure 3. Pods split along the suture to show that injury must be assessed on both sides. Seeds under each pod are presented in their original position within the pods revealing a good, but not consistent, association of moldy (black) and shrivelled seed with the extent of injury on the pod walls.

Herbicide-Rhizoctonia Interactions on Soybean Seedling Development

E. Bauske and H. Kirby

In 1986, Rhizoctonia damping-off and root rot, caused by *Rhizoctonia solani*, was prevalent in Illinois. Typically, plants up to one foot tall are affected. Infected plants often have a red lesion on the stem at the soil line and seedlings may damp-off. Additional effects include uneven stands and reduced yields. *R. solani* flourishes at relatively higher soil temperatures and lower soil moistures than other root-rotting fungi. It survives indefinitely in the soil as saprophytic mycelia and as sclerotia.

It has been suggested that this disease is increased by the use of preplant herbicides, particularly the dinitroaniline (DNA) group. Because theses herbicides account for a majority of the treated soybean acres, a study was conducted to determine if trifluralin, ethalfluralin, or pendimethalin affected incidence and severity of this disease and if a Rhizoctonia-specific seed treatment could reduce the damping-off phase of this disease.

The two-year study began in the summer of 1987 at two sites in Illinois, the Cruse farm in Champaign County, and the University of Illinois field station at Elwood in Will County. The three herbicides were applied at the recommended rates and incorporated immediately. A no-herbicide treatment was also included. Plots were planted to the cultivar 'Williams 82' and maintained with standard agronomic practices. One half of the seed used was treated with carboxin-pentachloronitrobenzine (Gustafson, Dallas, Texas).

Plots were inoculated with fungus-infested oat kernels at planting in the following manner. Oats were allowed to absorb water overnight and then autoclaved. They were then infested with mycelial plugs of *R. solani* and incubated for two weeks. The infested oats were air dried and applied during planting. Because oats may provide a food source for other soil microflora, a treatment of autoclaved, uninfested oats was added to the experiment to determine if the oats affect plant stand. Thus, inoculation treatments consisted of infested oats, autoclaved oats, or no oats. Both infested and uninfested oats were applied at a rate of 60 ml (about two ounces) by volume per 20-foot row. A two-row cone planter was used to plant seeds and apply inoculum. The level of disease produced by the inoculum was very high.

This split plot experiment had a randomized complete block design. The whole plots consisted of the four herbicide treatments. The subplots consisted of a seed treatment and an inoculum treatment. All subplots were 20 feet long by 4 rows wide. Early season plant stands and disease severities were evaluated. Disease severities were assessed by rating the hypocotyle lesion size.

One year of data indicates that there is no significant difference in plant stands between plots inoculated with *R. solani* with DNA herbicides, and inoculated plots with no herbicide. Furthermore, there was no significant difference in disease severity between inoculated plots with herbicide and inoculated plots with no herbicide. It appears that there is no interaction between Rhizoctonia disease and the three herbicides used. However, the seed treatment used did significantly increase plant stands, even though disease levels were far higher than are normally encountered. Though stands were very thin in seed treated plots, many of the untreated plots had no plants.

Overview of Weed Control for Soybeans

G. Kapusta

The recent introduction of several soil-applied and postemergence herbicides, used in combination with older herbicides, allows growers to achieve excellent control of almost all annual weeds in soybeans. Options are available for soil applications, for soil plus postemergence, and for postemergence programs. However, optimum, consistent control can be achieved only through the use of a systems approach. Crop rotation, proper seedbed preparation, a good fertility program, and proper planting of high quality seed, complemented by mechanical cultivation (as needed), greatly aids herbicides in controlling weeds by making the soybean crop more competitive. Knowledge of weed species in the field is also imperative to select the most effective herbicide program. Finally, proper application and incorporation (where appropriate), is the underpinning to make the entire system effective.

These basic practices are becoming more important each year for several reasons. Growers must reduce input costs to remain in business and selecting and properly applying the most cost-effective herbicide program is one way of doing so. The proper herbicide program will also decrease the likelihood of injuring the soybeans and causing a carryover to rotational crops as well as the likelihood of contaminating groundwater resources and terrestrial environment.

OLD VERSUS NEW SOIL HERBICIDES

Several new soil-applied herbicides of great value in achieving more complete weed control became available to soybean growers in 1986. Nonetheless, many older herbicides will remain as the foundation or at least a major component of weed control programs in the near future. The effectiveness, consistency, crop tolerance, and cost of the soil-applied grass herbicides are such that these products will continue to be used on the majority of the soybean acreage. The older broadleaf herbicides also will continue to be valuable components of soybean herbicide programs, although the magnitude of their use may decrease.

SOIL VERSUS POSTEMERGENCE HERBICIDES

The development and commercial availability of a wide range of very effective postemergence grass and broadleaf herbicides give growers the option of using a total postemergence program or a combination of soil and postemergence herbicides. Many reasons could be advanced for the advantages of this combination. However, the decision should be based on effectiveness of the herbicides on the weed spectrum in each field, relative cost, and how each program fits a grower's overall operation. Most situations would dictate the use of the most cost-effective herbicides, regardless of application type.

CHANGE IN TILLAGE PRACTICES: IMPLICATIONS

Considerable attention has been devoted to reducing tillage prior to planting crops, with no-till production as the ultimate cropping method. Reduced-till crop production is very similar to conventional-till in that essentially all options remain available. Herbicides can be incorporated and mechanical control can be performed. However, weed control in reduced-till systems frequently is more demanding because the previous year's weed seeds are incorporated to a near ideal germinating zone. Therefore, a substantially higher population of weeds may occur until the weed seeds in this zone are largely exhausted. Weed control in no-till soybeans remains less complete and less consistent than in tilled fields. Reliance is based primarily on preemergence herbicides that depend on timely rainfall for mobilization.

Furthermore, weeds emerged at application may not be controlled if they become excessively tall, as may occur during an extended period of rainfall. The development and adoption of the early preplant method has improved no-till weed control. Increased concern about soil erosion and possible governmental regulations regarding tillage may dictate an increase in no-tillage in the future.

IMPACT OF PREMIXES

A considerable number of herbicide premixes have been introduced in recent years--a great proliferation of these started in 1986--and there is no reason to suspect that this trend will diminish. Some premixes, such as Dyanap, Bicep, Sutazine, and Laddok, have been on the market for several years. Advantages of premixes are that only one container is needed instead of two or three, and they frequently cost less than if these products were purchased individually. Disadvantages are: (1) the constant introduction of product names that may be different from those of previous years, even though the products' components and ratios may be similar; (2) the possibility that the ratio of one or both components may not fit local conditions; (3) the need for expanded storage facilities for the many products brought to the market; and, (4) the difficulty of keeping up with all of the product names. Because manufacturers are likely to continue introducing new premixes, the marketplace will determine how many are accepted and will survive.

ROTATING HERBICIDES

Where broad spectrum, low cost herbicides are available, growers frequently use the same herbicide(s) for an extended number of years. This can lead to an increase in the population of weeds that are tolerant to the predominant herbicides used. Rotating crops has been an effective method in reducing these problems. Rotating herbicides can also be an effective measure in preventing or delaying the increase in these weed problems. However, for a rotation program to be successful, it is imperative that growers correctly identify all weed species in their fields, assess the likelihood of low density populations becoming a major problem, and select herbicides that will keep these species under control.

DIRECTED-SPRAYING

Complete, season-long control of all weed species with a single herbicide program is difficult. Mechanical cultivation can alleviate the problem between rows, but the weeds remaining within the rows may cause considerable competition later in the season. Directed-spraying is a low cost solution to this problem. Because most of the spray is directed away from the soybean leaves, a wide range of chemicals can be used safely. There is a great need to label additional herbicides for this method, especially several nonselective, contact-type herbicides.

CARRYOVER CONCERNS

Most of the herbicides used in past years caused little concern about carryover to rotational crops. The recent commercialization of Scepter and chlorimuron (a component of Preview, Canopy, Lorox Plus, and Gemini), however, poses a concern in this regard because these herbicides can persist in the soil beyond the soybean cropping season. Considerable research is being done throughout the United States to record the factors involved where carryover has been documented and to develop guidelines to avoid the problem. Accurate application of the recommended herbicide rate is the primary solution to carryover problems.

PERENNIAL WEEDS

The ability to achieve more complete control of annual weeds with current herbicides and the reduction in tillage has resulted in an increase in perennial weeds. Common milkweed, honeyvine milkweed, hemp dogbane, hedge bindweed, trumpet creeper, bigroot morningglory, and other perennials are becoming production problems more frequently. Moldboard plowing, cultivation, and the use of 2,4-D and/or Banvel between cropping seasons and in rotational crops, such as corn, are the major methods available for control of these weeds. Because they usually are restricted to small areas of a field, spot treatment with a nonselective herbicide also would be a viable alternative to control perennials.

IMPACT OF GOVERNMENT PROGRAMS

Millions of acres of cropland have been diverted to "set-aside" programs in recent years. These acres present both a problem and an opportunity regarding weed control. Weed control on many of these acres has been less than complete, resulting in a tremendous production of weed seed that will cause problems when the land is returned to crop produciton. The opportunity available in these acres is the control of perennial and hard-to-control annual weeds with herbicides that cannot be used on row crops or wheat. Growers need to take advantage of these opportunities, and local dealers and custom applicators can be influential forces in aiding them.

ENVIRONMENTAL CONCERNS

Considerable attention is being directed nationally to monitoring groundwater for possible pesticide pollution. To minimize these concerns, those involved in the sale or use of pesticides should be most conscientious when using or promoting the use of these products. The Endangered Species Act, which will go into effect in 1988, will also have an impact on pesticide use. Although details of this legislation are not yet complete, the implementation will restrict or prohibit the use of certain pesticides in counties where endangered species have been identified. The impact could result in a sharp reduction in the use of pesticides in many areas.

BIOTECHNOLOGY

Several companies are progressing rapidly in taking advantage of biotechnology to develop products that may greatly change current pest control efforts. In the future, we may see crops tolerant to nonselective herbicides or to higher rates of selective herbicides. We may see more use of products derived from natural sources for insect control, and substantially improved crop tolerance to plant diseases.

Insects in Stored Grain: Illinois Survey Findings and Management Recommendations

R. Weinzierl and P. Porter

Over 4 billion bushels (over 100 million metric tons) of carryover shelled corn remained in storage as corn harvest began in September of 1986. In late summer of 1987, agricultural economists estimated that the carryover corn supply exceeded 5 billion bushels. Much of this corn will remain in storage for extended periods under loan and storage programs administered by the United States Department of Agriculture's Agricultural Stabilization and Conservation Service (ASCS). This tremendous buildup of grain supplies convincingly illustrates the fact that successful long-term storage and marketing have become as important as successful production of corn in the midwestern United States.

Insect infestation of stored grain, especially grain in long-term storage, is known to be common and costly in the north central United States (Barak and Harein 1981; Storey et al. 1983). Storey et al. (1983) found that in 68 of 95 bins, corn stored under the ASCS reserve program in Illinois for one or more summers and sampled in late summer was infested by pest insects. Infestations averaged 16 insects per kilogram of corn; this degree of infestation would result in substantial price discount or rejection of the infested corn at the time of attempted sale. These results, coupled with additional findings from export samples (Storey et al. 1982) and stored-grain pest management surveys (Storey et al. 1984), indicate that adequate pest management practices are too often neglected in the management of stored corn.

Although the studies discussed previously adequately document the argument that recent efforts in stored-corn pest management have been insufficient, many questions remain unanswered. For example, although Storey et al. (1983) provided a useful description of pest problems in corn stored through one or more summers (and in some instances up to four years), their findings cannot be interpreted as representative of all corn stored in Illinois. Knowledge of the incidence and degree of insect infestation and economic losses under a range of storage conditions and during different seasons is necessary for the development and adoption of improved pest management practices.

The corn sampling program and the questionnaire described in this paper represent a portion of our efforts to evaluate and improve pest management practices for stored corn. We demonstrated and evaluated the use of available sampling equipment for the detection of insects in stored grains. We interviewed grain managers (farmers and elevator operators) to determine their storage practices, and additional elevator operators completed questionnaires describing management practices and pest-related losses. The results presented in this paper represent a preliminary report of our findings.

MATERIALS AND METHODS

Bin Survey and Manager Interviews

From September, 1985, through August, 1986, we conducted a statewide survey of stored-corn insect infestations and grain management practices. We examined 65 storages controlled by 48 different managers in 21 Illinois counties. Five bins were sampled on two separate dates; all other storages were sampled only once. We also interviewed the manager (farmer or elevator operator) of each storage to collect information on storage practices and to provide recommendations for future management. The objectives of this sampling and interview project were:

- --to demonstrate and evaluate the usefulness of available sampling tools for monitoring insect infestations in stored corn;
- --to determine insect infestation levels in individual bins;
- --to measure additional factors related to grain quality and/or storability such as moisture, temperature, and levels of broken corn and foreign material (BCFM);
- --to collect information on management practices and to describe any relationships between storage practices and insect infestations;
- --to report results to individual managers and provide recommendations for necessary actions; and,
- --to build an information base that will be useful in establishing future management recommendations and Extension programs.

In each storage, corn samples were collected from five sections (north, south, east, west, and center). In each section, samples were taken from the surface (using a 1-quart scoop), at depths of 3 and 9 feet (using a deep bin probe), and from a depth of 0 to 5 feet (using a compartmentalized grain trier). This sampling scheme produced 20 samples from each storage. We measured temperatures at the grain surface and at depths of 3 and 9 feet in each section of each storage.

We also used unbaited pitfall traps ("Grain Guard" grain probe traps manufactured by Grain Guard Inc., 205 Legion Street, Madison, Wisconsin 53593, (608)845-5160) to detect insects. Barak and Harein (1982), Loschiavo and Atkinson (1973), and Wright and Mills (1984) have reported on the development and use of these and similar traps. Traps were placed just below the grain surface and at a depth of 9 feet in each section of each bin (a total of 10 traps per bin) and removed three to four days later.

All corn samples were bagged on site and processed in the laboratory. Samples were weighed, sieved over a 12/64 round sieve, and reweighed to determine percent BCFM. Moisture content was determined using an approved 72-hour oven drying method. We examined screenings from each sample to identify and count the insects present.

Interviews and observations at each storage answered the following questions:

- --What are the dimensions and volume of the storage?
- --When was the corn harvested? When was it moved into this storage?
- --Was long-term storage (greater than six to eight months) planned at the time the grain was binned?
- --Was the storage emptied and thoroughly cleaned before this corn was binned?
- --Was an empty-bin spray applied before filling?
- --Was a grain cleaner used?

--Was a grain spreader used?
--Was a protectant insecticide applied at the auger as the corn was binned?
--Was the grain surface level at the time of sampling?
--Was the grain surface "topdressed"? With what insecticides?
--Were dichlorvos resin strips used?
--What grain drying and aeration equipment have been used?
--Were stirrators used?
--Had the grain been fumigated? What fumigant and when?

Grain Elevator Management Questionnaire

In the summer of 1985, a questionnaire was mailed to approximately 600 Illinois elevator managers; all were members of the Grain and Feed Association of Illinois. We received 159 responses to this questionnaire; all but seven of those responding identified their facility as a "country elevator." Elevator managers supplied answers to the following questions and requests about their grain management practices during the preceding five years. (Questions and requests are presented in an abbreviated form; questionnaires contained sufficient detail to avoid confusion and provide structure for responses.)

--Estimate seasonal trends in corn deliveries (categories specified).
--Estimate the percentage of corn stored one year or longer before delivery.
--What percentage of corn was treated with malathion before delivery to your facility?
--What percentage of corn was treated with *Bacillus thuringiensis* before delivery to your facility?
--What percentage of corn was fumigated before delivery? (Separate classes of fumigants listed for specific responses.)
--What percentage of deliveries have contained live insects or insect damage?
--Estimate seasonal trends for insect problems (categories specified).
--What criteria do you use for assessing discounts based on insect problems?
--What is the discount (how many cents per bushel) applied to insect-infested corn?
--Estimate the percentage of insect-infested corn that you (1) accepted without discount, (2) accepted, but assessed a discount, and (3) rejected.
--Describe how long you have stored corn at your facilities (categories specified).
--Estimate the percentage of corn in which insect problems developed while the corn was stored at your facilities.
--What percentage of your corn have you treated with malathion?
--What percentage of your corn have you treated with *Bacillus thuringiensis*?
--What percentage of your corn have you fumigated? (Separate classes of fumigants listed for specific responses.)

Results and Discussion

We note that our selection of cooperators in this project (those who managed the bins we sampled and those who filled out questionnaires) cannot accurately be termed "random." County Extension advisers and ASCS personnel aided us in locating storage facilities, and although no intentional bias toward good or bad managers was intended, it might be argued that the managers they selected are not representative of the overall populations of farmers or elevator managers in Illinois. Additional elevator operators who completed storage questionnaires were identified because of their membership in The Grain and Feed Association of Illinois. We also recognize that questionnaires gather the information that respondents want to provide; the accuracy of that information can be questioned. Despite these limitations, the following data provide a useful and extensive description of grain storage practices and insect problems in Illinois.

Bin Survey and Manager Interviews

Only a general review of our sampling results will be presented in this paper. Many specifics concerning spatial distribution and abundance of individual species, relationships between insect counts from traps and corn samples, and relationships between storage conditions and specific insect densities have not yet been analyzed adequately.

A brief review of the types of stored-grain pests will provide some context for our findings. The insect pests that inhabit stored grain can be grouped into three broad categories: (1) the weevils and other "primary" pests that develop within grain kernels; (2) the beetles that feed externally on damaged kernels, "fine material," and molds (these are often termed "secondary beetles," "bran bugs," "fungus feeders," or simply "external beetles"); and, (3) the caterpillars that feed mainly near the surface of the grain mass. No one term adequately describes all the beetles lumped together under Category 2, but for simplicity these insects will be referred to as secondary beetles because they are most often associated with grain already damaged in some way (by weevils, molds, or breakage). The Indianmeal moth is the most common of the caterpillars and moths that infest stored grain in Illinois. Throughout the Midwest, populations of this pest are resistant to the insecticide malathion. Other insects and mites that are not described by these broad categories do inhabit stored grains; no discussion of these species is included in this paper.

General knowledge of grain storage practices and stored-grain insect management will help in understanding the findings presented in the following paragraphs. See Christensen (1982), Raney (1987), and Weinzierl (1986; 1988) for background.

The 65 storages sampled in this survey project contained 9.3 million bushels of corn; 8.3 million bushels of this total were stored in eight commercial facilities. The remaining 1 million bushels in 57 storages represent an average capacity of 17.5 thousand bushels per storage. The length of time corn had been stored at the time of sampling ranged from less than one month to forty-four months.

Of the 65 storages, 33 were sampled between October 1 and April 30; 32 were sampled between May 1 and September 30. This distinction is important because managers can, in most instances, use aeration to cool stored grain and limit any insect problems during the fall, winter, and early spring. In our survey, however, temperatures at one or more sites in 5 of the 33 storages (15 percent) sampled between October 1 and April 30 exceeded 80°F. In 5 of 32 storages (16 percent) sampled between May 1 and September 30, temperatures at one or more sites exceeded 100°F. In one large commercial tank sampled in August 1986, grain temperature at the peaked center of the bin had reached 122°F, while temperatures of 40°F were detected within the grain mass approximately 40 feet from the peak. These observations of exceptionally high temperatures and extreme variations in temperatures within a storage, whether in winter or summer, are evidence of inadequate aeration practices. The resulting moisture migration, molding, and heating of corn (a result of metabolic heat released during mold growth) reduce the quality of the stored grain and render it more suitable for subsequent insect infestation.

Failure to level the grain surface was a problem in many bins. Of the 65 storages sampled, the grain surface remained peaked in 43. Where stored grain is not levelled, air flow during aeration is not uniform unless the aeration system is designed appropriately. We sampled 17 "flat" storages (including four converted ear-corn cribs); the grain surface in 11 of these was not levelled. Aeration systems in many modern flat storages are designed to provide proper air flow through peaked grain. Consequently, we cannot consider these flat storages to have been mismanaged simply because the grain surface was not levelled. However, in 31 of 48 round bins (65 percent), the grain surface remained peaked at the time of sampling. The results of inadequate aeration were very obvious in 14 of these 31 bins, as heating and/or solid masses of blackened kernels in the peaked grain provided evidence of extensive mold growth and spoilage.

Few managers had cleaned corn to remove fine material before binning. Grain cleaners of any kind (even relatively inefficient perforated sections in augers) had been used at only 14 of the 65 storages (22 percent). Fine material in the centers of bins reflected the failure to clean corn before storage: BCFM levels in center samples exceeded 3 percent in 33 of 64 bins; of these, center BCFM exceeded 5 percent in 22 and exceeded 10 percent in 8. BCFM levels from all bins averaged 6.4 percent for center samples and 1.4 percent for "outer" samples (from north, south, east, and west sections). These findings are important because many insect pests of stored grains thrive only in the presence of damaged kernels and grain debris. The fine material in stored grains also promotes greater losses to storage molds.

Managers of 49 of the 65 storages reported that at the time they binned their corn they intended to store it at least nine months. Where plans include storing corn into midsummer or longer, farmers and elevator operators should be especially sure to empty and clean storage facilities before binning, and use a grain mass or topdress application of a protectant insecticide to limit insect infestations. However, at 11 of the 49 storages (22 percent), managers had failed to empty or clean the facility before adding new corn. The most common mistake was to add new corn atop carryover corn already in the storage. This practice invites the movement of insect pests from carryover grain into the new crop. Another valuable sanitation step, the application of an empty-bin spray to the walls and floor of the storage before adding new grain, was completed in only 24 of the 49 storages (49 percent). At eight facilities, managers applied a protectant insecticide (malathion) at the auger or conveyor belt as corn was moved into storage, but in only two instances was this insecticide applied uniformly to all the corn as it was binned. (In the other instances, some loads or portions of the storage were treated, but others were not.) Infrequency of insecticide use is best exemplified by reviewing records from the sites where corn had already been stored for an extended period. We sampled in 52 facilities where corn had been stored seven months or longer; corn in these storages should have been treated in some manner before we sampled. Corn in seven of these storages had been treated as it was binned; topdress applications had been made in six storages; the other 39 (75 percent) had not been treated with any protectant insecticide.

Where corn remained in storage for periods exceeding six months (and therefore remained in storage as outdoor temperatures warmed), insect infestations were common. Live insects were detected from corn samples in 28 of 29 storages sampled between June 1 and October 30. Traps captured live insects in all 29 of these storages.

Although our purpose in this paper is to provide a general summary of insect infestations, some discussion of individual species is necessary. "Primary" pests, those that develop within kernels, were not common in the storages we sampled. Rice weevil [*Sitophilus oryzae* (L.)] and maize weevil (*Sitophilus zeamais* Motschulsky) were collected in several bins, but the granary weevil [*Sitophilus granarius* (L.)] was very rare, and we discovered no lesser grain borers [*Rhyzopertha dominica* (Fabricius)] in any samples. Common "secondary beetles" included flat and rusty grain beetles (*Cryptolestes* spp.), foreign grain beetle [*Ahasversus advena* (Waltl)], hairy fungus beetle [*Typhaea stercorea* (L.)], larger black flour beetle [*Cynaeus angustus* (leConte)], sawtooth grain beetle [*Oryzaephilus surinamensis* (L.)], red flour beetle [*Tribolium castaneum* (Herbst)], and square-nosed fungus beetle [*Lathridius* (= *Enicmus*) *minutus* (L.)]. A complete listing of insects and mites collected in this survey will be published once all species determinations are made or confirmed by identification specialists at the USDA Insect Identification and Beneficial Insect Introduction Center in Beltsville, Maryland.

Overall findings are best summarized by grouping insects into the three broad categories outlined previously (weevils, "secondary beetles," and Indianmeal moth) and examining their prevalence according to the length of time grain has been stored and the location of samples within storages (Table 1). As indicated in Table 1, almost no insects were collected in corn samples where the grain had been stored for six months or less. Fall harvest and cold winter temperatures offer an obvious explanation for this finding. The most numerous pests in our survey were the secondary beetles, not the weevils (*Sitophilus* spp.). In all of our corn samples we collected only 468 weevils, and 440 of those were in samples from just two heavily-infested storages. In the same samples we collected over 2,500 secondary beetles. Pitfall traps produced similar findings; traps collected 2,746 weevils (2,646 from only two heavily infested bins) and over 63,000 secondary beetles.

Grain probe traps (pitfall traps) captured hundreds and even thousands of insects in some bins. In one heavily infested bin sampled in July of 1986, 10 traps left in the grain for four days contained over 20,000 insects. Although such massive captures vividly indicate that extremely high numbers of insects can be present in grain, trapping and sorting thousands of insects usually provided little new information. In bins where traps contained thousands of insects, we also readily detected insect infestations in corn samples collected using conventional sampling tools. These traps probably offer a greater usefulness as very sensitive detectors of low-density infestations (Weinzierl and Porter 1987). In 38 bins where grain temperatures were greater than or equal to 60°F at one or more sample sites, traps captured weevils at 46 of 380 sample sites and secondary beetles at 285 of 380 sample sites. Traditional sampling techniques were less effective in detecting these insect infestations. In corn samples from matching sites in the same bins, we found weevils and secondary beetles in just 15 and 137 samples, respectively. In these 38 bins, traps captured weevils in 16 bins; we found live weevils in corn samples from only five of the same bins. Although the traps are very useful in warm grain, it is important to note that trap effectiveness depends upon insect activity. As grain temperatures drop, traps become less effective. Differences in species responses to temperature changes are not yet well understood, nor are the relationships between insect counts in traps and absolute measures of insect density in grain.

Grain Elevator Management Questionnaire

Elevator managers responded to our questionnaire in the summer of 1985 and described grain conditions, storage practices, and insect problems over the previous five-year period. Note that the amount of corn in storage and the length of time that corn remains in storage have increased dramatically since this survey.

The following summary is based on responses from managers of 152 country elevators located throughout Illinois. Not all managers answered every question in this questionnaire, so some findings are based on fewer respondents. Reports of average annual corn volumes from 149 elevators totalled 220 million bushels for an average of approximately 1.5 million bushels per facility. Responses from 151 facilities were averaged to summarize seasonal patterns in delivery from the farm as follows:

--66 percent of annual corn volume received from Oct. 1 through Dec. 31
--16 percent of annual corn volume received from Jan. 1 through Mar. 31
--10 percent of annual corn volume received from Apr. 1 through June 30
-- 8 percent of annual corn volume received from July 1 through Sept. 30

Elevator managers also estimated that, on average, 6.9 percent of the corn delivered to their facilities had been stored one year or longer on the farm before delivery. Although farm program loan rates, storage agreements, and increased corn supplies have resulted in a seasonal delivery pattern that currently differs greatly from that reported in 1985, the seasonal patterns summarized previously are useful in the evaluation of additional answers provided in this questionnaire.

Averaging responses from 71 country elevators resulted in an estimate that 2.1 percent of the corn delivered to these facilities during the previous five years had been treated with malathion at the farm some time before delivery. Elevator operators estimated that less than 4 percent of the corn they received had been fumigated during on-farm storage. They reported that most of these fumigations involved the use of liquid fumigants containing EDB and/or carbon tetrachloride; use of these fumigants has since been prohibited by the United States Environmental Protection Agency.

Elevator managers' estimates of insecticide usage on farm-stored corn must be recognized as opinions and estimates, and not as true measurements. Nonetheless, these estimates, like our sampling program, indicate an underuse of insecticides on farm-stored corn. Effective management should include at least topdress application of an insecticide to corn stored on the farm beyond the first of July (8 percent of all deliveries to commercial elevators were received between July 1 and September 30) and to corn held in storage for one year or longer before delivery (6.9 percent of all deliveries). Estimates that only 2.1 percent of all corn was treated with malathion (the only broad-spectrum protectant available at the time of this survey) at the farm mean that the majority of the corn that should be treated because it is held in storage for nine months or longer remains unprotected.

Elevator managers reported insect damage or live insects in an average of 3.1 percent of all corn they received. As expected, problems were concentrated in summer deliveries. Less than 5 percent of all insect-damaged or infested corn was delivered between October 1 and March 31. Although July 1 through September 30 deliveries represented only 8 percent of the annual volume at these facilities, managers estimated that 71 percent of all insect-damaged or infested corn was delivered during this period. These findings reinforce the conclusion that farmers too often neglect to practice adequate pest management where corn remains in storage during summer months. Current increases in long-term on-farm storage, if coupled with continued inadequate management will almost certainly lead to infestations and damage in much more of the corn delivered to country elevators.

The average price discount charged by elevator operators for the presence of live insects in corn in 1985 was 5.6 cents per bushel. Discounts have increased since 1985 as a result of increased corn supplies and limited storage space, but more recent summaries of discounts are unavailable. Managers reported that they accepted, but levied discounts on 81 percent of the insect-infested corn they received; they rejected 3.5 percent of the insect-infested corn brought to their facilities. Elevator operators accepted without discount approximately 16 percent of the insect-infested corn brought to their facilities. This step, although beneficial to a few producers who failed to adequately manage their stored corn, probably contributes to grain quality problems. Accepting damaged grain without discount resoundingly reinforces the idea that there is little reason to effectively manage stored grain and deliver a premium quality commodity if substandard grain can be sold for the same price.

Some of the same management problems apparent in on-farm storage appear to continue in commercial storage. This conclusion results from examining pest management practices in relation to the length of time corn is stored at elevator facilities. Elevator managers reported that 72 percent of the corn they received remained in storage at their facilities no more than six months, 20 percent was stored six to twelve months, and 8 percent was stored for more than one year. (Again, although current estimates for 1987-88 have not been assessed for this report, long-term storage at elevator facilities is now much more prevalent.) The 1985 storage patterns indicate that 28 percent of the elevators' corn supplies remain in storage longer than six months and should receive at least a topdress application of a protectant insecticide. Operators reported that only 11.4 percent of all corn is treated with malathion at their facilities. They reported use of *Bacillus thuringiensis* for Indianmeal moth control on only 2.1 percent of their stored corn. Insect infestations developed in 7.6 percent of all corn stored at the these elevators. Managers reported fumigating approximately 10.1 percent of all corn at their facilities (6 percent with liquid fumigants, 3.9 percent with aluminum phosphide products, 0.2 percent with methyl bromide, and less than 0.1 percent with carbon dioxide or nitrogen).

CONCLUSIONS AND RECOMMENDATIONS

Two statements broadly summarize most of our observations: 1) too many farmers and elevator operators did not invest sufficient management efforts to protect against insect infestation and grain damage; and, 2) inadequate management was evidenced by insect infestations and mold damage in many bins.

In Illinois, storing corn successfully for six to nine months following harvest can be accomplished by adequately drying the crop, providing shelter, and aerating to manage grain temperatures. Storage for up to a year can be achieved with proper nonchemical practices and minimal use of protectant insecticides (empty-bin sprays and topdress applications). Unfortunately, too few managers (elevator operators or farmers) adequately completed all necessary steps in bin sanitation, grain cleaning, levelling, and aeration, even where long-term storage was planned. Although several managers held corn in storage for longer than one year, few used topdress or grain-mass applications of insecticides.

The insect infestations that developed in untreated corn stored during summer months or for more than one year were comprised mainly of "secondary beetles" associated with broken kernels, grain debris, and grain fungi. Fortunately, these insects can be removed from corn before sale by using a grain cleaner and applying malathion to the corn as it is moved from storage. Removing insects just before sale is, however, just as expensive as using proper preventive steps, and predelivery cleanup fails to protect corn from kernel damage and increases in grain moisture and temperature resulting from insect metabolism.

We can discuss some aspects of the economic losses that result from insect management efforts and insect infestations, but a thorough assessment of such losses is complicated by many factors. If elevator managers' estimates are used, one portion of total losses can be calculated for 1981 to 1985 by applying a 5.6 cents per bushel discount on 3.1 percent of all corn delivered from the farm. In addition, elevator managers reported that 10.1 percent of all corn passing through or stored in their facilities was fumigated, and they estimated that approximately 4 percent of the corn they received from the farm was fumigated before delivery. Fumigation costs for this corn can be estimated conservatively at 0.7 to 1 cent per bushel where aluminum phosphide fumigants were used and 3 to 5 cents per bushel where liquid fumigants were applied. Elevator managers estimated that malathion was applied to 2.1 percent of all corn delivered from the farm; 11.4 percent was treated at elevator facilities. The cost of malathion treatments average 0.3 to 0.5 cents per bushel. We did not measure losses caused by insect consumption of grain and reduction in test weight; such losses can be severe where primary pests such as weevils and lesser grain borer are prevalent.

The costs outlined here might be used to generate a figure describing the total losses associated with stored-corn insects, but such figures should be computed yearly according to storage practices and grain prices. More importantly, losses derived in this way do not include consideration for lost markets or depressed prices associated with international buyers' perceptions of United States corn quality. Effective stored-corn pest management need not be costly. Improved practices should pay off in both immediate and large-scale benefits--reduced discounts and improved quality in international markets.

Extension Circular 1242, *Insect Pest Management for Stored Grain* (Weinzierl 1988), presents detailed recommendations concerning storage practices and insecticide uses for the prevention of insect damage in stored grains. An important component of these recommendations is consideration of the length of time corn will remain in storage. Where corn is to be stored nine to twelve months, bin cleanup, the use of a grain cleaner, levelling, and aerating the grain in storage are very important. Topdress applications of Actellic or of malathion plus a *Bacillus thuringiensis* product will adequately protect corn for one summer's storage if applications are made by early May. Safe storage of corn for more than one year requires the application of an insecticide to the entire grain mass as corn is augered into storage. Published studies (Cogburn 1976; LaHue 1976, 1977; Quinlan et al. 1979; Watters 1959; Watters and Mensah 1979) and research underway in Illinois indicate that treating corn at the auger with malathion or Actellic can protect against infestation by beetles and weevils for over one year. Actellic also controls Indianmeal moths, as do formulations of *Bacillus thuringiensis* (Dipel, Topside, SOK-Bt, and Thuricide). Where storage under multiyear programs is planned and grain mass treatments are not made, annual rollover of stored corn can be practiced to avoid excessive buildup of insects.

Corn can be stored safely and economically for extended periods when recommended pest management practices are completed. What is most needed is for farmers and elevator managers to utilize the management methods available.

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Table 1. Insect Densities in Corn Samples[a]

Sample site[b]	Storage duration[c]	Weevils	Secondary beetles	Indianmeal moth
Center	≤ 6 mo.	0	0	0
Surface	> 6 mo.	0	13	1.3
Center	≤ 6 mo.	0	0	0
Subsurface	> 6 mo.	0	12	0
Outer	≤ 6 mo.	0	<1	0
Surface	> 6 mo.	3.3	9.1	<1
Outer	≤ 6 mo.	0	0	0
Subsurface	> 6 mo.	<1	3	0

[a]Number of live insects per 1,000 grams of corn.
[b]Counts from north, south, east, and west samples from each storage were pooled to generate data for "Outer" sample sites. Counts for "Subsurface" sites were pooled from samples collected with a compartmentalized grain trier and samples collected at depths of 3 and 9 feet using a deep bin probe.
[c]Corn in 17 storages had been stored six months or less; corn in 46 storages had been stored longer than six months. Data from two storages sampled in this project were not included in this summary because sampling methods differed from those used at other bins.

Effects of Low Rates of Fungicides on Storage Molds of Corn

D. White, J. Shriver, and R. Sholtis

INTRODUCTION

Currently, our control of storage molds relies on the integration of three controls: (1) prevention of mechanical damage during harvest and transportation of grain (an intact kernel of corn is much more resistant to penetration by fungi than a kernel that has been cracked or broken); (2) moisture levels below those that are optimum for fungal growth; and, (3) grain temperatures below 40°F (which can occur in much of the Midwest from October to March).

INTEGRATION OF CURRENT CONTROLS

With these three controls available, the common practice is to use high temperature drying to dry corn to 15 to 16 percent moisture and then maintain this moisture as long as temperatures are cool. Corn can be stored in much of the Midwest from harvest through the spring with a combination of cool temperature and moistures of 15 to 16 percent. During spring, some kernels that have higher moisture due to moisture migration or uneven drying may begin to decay due to fungal growth at warmer temperatures. Additional moisture and heat are produced by fungal metabolism, thus creating favorable conditions for fungal growth in very large areas of the grain mass. To prevent this, corn to be kept through the summer is often dried to 13.5 to 14.0 percent moisture, thus moving to moisture levels less conducive for fungal growth. Drying to 14 percent moisture or below, however, is not desirable because of shrink discounts and because corn at low moisture, particularly with stress cracks, is more subject to breakage than corn of higher moisture.

HOW FUNGICIDES FIT INTO AN INTEGRATED SYSTEM OF CONTROL OF STORAGE MOLDS

The three current controls used to prevent growth of storage fungi in corn are not adequate to protect the commodity and maintain high quality. During the past five years at the University of Illinois, the Department of Plant Pathology has developed facilities for testing fungicides to prevent spores of fungi from germinating and penetrating individual kernels of corn. This type of control is used in the preservation of a number of high-moisture commodities such as fruits and vegetables. With high-moisture commodities, low temperatures are a major control of decay-producing organisms. Over the last twenty-five years, temperature and fungicides have been used together to prevent storage diseases in fruits and vegetables. Experiments at the University of Illinois have combined the use of fungicides and low temperature drying to result in better quality grain. This research has been funded by a number of chemical companies, as well as the Illinois Corn Marketing Board, Quaker Oats, and the Anderson Research Fund. These studies have resulted in a Section 18 (emergency exemption) for Illinois under

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the provisions of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) to the Illinois Department of Agriculture for the use of MERTECT 340-F to suppress growth of *Aspergillus* and *Penicillium* species on corn grain until January 1988. MERTECT 340-F should have a full Federal label by the fall of 1988 and hopefully other fungicides will be labeled soon.

The advantages of using fungicides in an integrated system to control storage fungi are not completely clear at this time. Care should be taken to understand the limitations of fungicide use so their advantages will not be overstated.

1986-87 RESEARCH

On-Farm Testing

Merck and Co. conducted studies in numerous locations in Illinois and other states. Most of these studies involved a comparison of a bin treated with MERTECT 340-F and an untreated bin. For the purpose of this report, four such locations were selected where treated and untreated bins could be compared (Table 1). All fungicide treatments of .03 fl oz MERTECT 340-F per bushel in 3 oz water carrier were made using a treater auger available at Paul's Machine and Welding in Villa Grove, Illinois. It is necessary to point out that data from unreplicated on-farm bin experiments are difficult to interpret because moistures in bins are not always identical. Additionally, the corn used to fill one bin may be of a different hybrid than corn used to fill another bin. Data presented here represent an average of samples taken from four quadrants in the upper three to six feet of grain in the bin. The percentage of *Penicillium* spp. and the percentage of *Aspergillus* spp. is based on isolations from 50 kernels per sample plated on malt salt agar. The percent damaged is based on results from federal grain inspection.

The data from Farm Study One are probably the most useful. At this farm, the harvest moisture was 20 to 22 percent and one untreated bin could be compared to two different treated bins. In January, the moisture was 20 percent or above and there was very little storage fungi activity. In March, the percent *Penicillium* spp. increased in the untreated bin but was controlled by the MERTECT 340-F in both treated bins. The grain moisture in the untreated bin was reduced to 17 percent. In April, corn in the untreated bin continued to have *Penicillium* spp. activity and corn in the two treated bins had little or no *Penicillium* spp. activity even though grain moistures were at 20 percent. In May, corn in the untreated bin started to go out of condition and the grain moisture was reduced to 13.3 percent. At this time, corn in the untreated bin had an 8.6 percent damage and corn in the two treated bins had less damage even though the moisture had been maintained at a higher level. Corn in the second treated bin, however, did have *Penicillium* spp. activity. In August, corn in the two treated bins still had much less damage but did have some *Aspergillus* spp. activity. Corn in the untreated bin, however, had 21 percent damaged kernels. In this experiment it was evident that corn treated with fungicide could be at a fairly high moisture with minimal damage.

The data from Farm Study Two represent a situation where no advantage was seen due to treatment of fungicide. At this location the harvest moisture was 16 to 17 percent and corn was kept at 13 to 15 percent grain moisture. In both treated and untreated bins, the activity of storage molds was minimal and damage was below 1 percent.

In Farm Study Three, the harvest moisture was not known and only one sample was taken in May. It was known, however, that the two bins were filled at the same time with corn from similar fields. In this situation, corn in the untreated bin had *Aspergillus* spp. and *Penicillium* spp. activity and a percent damage of 26.2 percent. Corn in the treated bin had much less storage fungi activity and much lower percent damage.

In Farm Study Four, the harvest moisture was 17 to 18 percent and was not dried below 15.2 percent. In this study it was unfortunate that the control bin was kept at a higher moisture than the treated bin. This may help to explain the bad condition of corn in the control bin at the final sampling in July.

Several conclusions can be made from the farm studies presented in this report and other farm studies done by Merck and Co. In all studies, treated corn did have less fungal activity than untreated corn. However, in some bins where corn was held at a high moisture, storage molds were active and damage did occur even though grain was treated. It is necessary to continually emphasize that fungicides are part of an integrated pest management system and are not a "cure-all" allowing for avoidance of other management techniques.

University of Illinois Experiments

Three separate experiments were conducted at the grain storage facilities at the University of Illinois. Experiment One was to determine the effects of high temperature drying on the efficacy of MERTECT 340-F. Experiment Two was to determine the effect of various methods of application of MERTECT 340-F in conjunction with low temperature drying. Experiment Three was to determine the effectiveness of Iprodione, which is a compound from Rhone-Poulenc Corporation, Inc., and was identified in laboratory testing during 1986 as a possible candidate for control of storage fungi in corn.

Experiments were conducted in two modified 2700 bushel grain bins located at the Agronomy-Plant Pathology South Farm, Urbana, Illinois. Each bin has 16 wedge-shaped compartments that contain various treatments. Each wedge has sample ports that allow samples to be taken at various distances from the grain drying floor to the top of the bin. For the data reported here, samples were taken from 1.2, 2.4, and 3.6 meters (bottom, middle, and top, respectively) from the drying floor. All experiments were in two replicates. Data on fungal isolations are based on the average of fifty kernels from each of two replicates and the three sampling levels. Percent damaged kernels is based on federal grain inspection of samples from three sampling levels and the two replicates.

High Temperature Drying--Experiment One. In the experiment with high temperature drying, the treatments were untreated high temperature dried, treated with 0.03 fl oz MERTECT 340-F per bushel using 3 oz of water carrier after drying, treated with 0.03 fl oz MERTECT 340-F per bushel using 0.2 fl oz of mineral oil as a carrier, and treated with MERTECT 340-F per bushel using 3 oz of water carrier before drying. The main purpose of this experiment was to determine if high temperature drying caused any reduction in the efficacy of MERTECT 340-F due to chemical breakdown with heat.

Corn was harvested on September 23, 1986, at approximately 21 percent moisture and was dried to 17 percent moisture using an M & W Batch Dryer. The plenum temperature was kept at 200°F and grain was heated to 140°F to obtain the moisture of 17 percent (Figure 1). Grain moistures were further reduced by ambient air drying with a flow rate of 0.5 CFM per bushel of air flow to an average of grain moisture of 15 to 16 percent. These moistures were then maintained for the duration of the experiment. As was expected, the amount of *Penicillium* spp. occurring in the high temperature experiment was very low (Figure 2). In all cases, treatments controlled the *Penicillium* spp. throughout the duration of the experiment. With respect to *Aspergillus* spp., the MERTECT 340-F with mineral oil carrier before drying and the MERTECT 340-F with water carrier before drying provided the best controls (Figure 3). This result may have been due to the circulating activity of the batch dryer, which may have resulted in better distribution of the fungicide on the kernels. The results of percent damaged kernels were similar to the results with *Aspergillus* spp. in that damage was lower with the treatments applied before drying (Figure 4).

Low Temperature Drying with Various Methods of Application of MERTECT 340-F--Experiment Two. Three different methods of application of MERTECT 340-F were compared to an untreated control. One method of application was with a plexiglass hood that was built over part of the boot of the fill auger. This hood restricted grain flow and completed a spray chamber in which grain was exposed. With application at the boot, two different methods were used. One was to use 3 fl oz of water as a fungicide carrier and the other was to use 0.2 fl oz of mineral oil as a fungicide carrier. The fourth treatment was the use of the treater auger that had been used in previous experiments. In this experiment grain was harvested at approximately 20 percent moisture treated with various fungicide treatments and placed into the bins for drying. Grain moisture levels at the bottom sample level were allowed to drop to approximately 15 percent. Grain at the middle sampling level was approximately 16.5 percent moisture and approximately 17.5 percent grain moisture at the top sampling level. These moistures were maintained through the first 31 weeks of the experiment. After the first 31 weeks, the fans again were turned on, which further reduced grain moistures (Figure 5).

All three methods of application were successful in reducing percent *Penicillium* spp. (Figure 6). This was not the case with respect to *Aspergillus* spp. in that the application with 0.2 fl oz of mineral oil was not successful. The treater auger, however, was successful as was the application of MERTECT 340-F with water carrier applied at the boot (Figure 7). Percent damage had results similar to the total *Aspergillus* spp. in that MERTECT 340-F with 0.2 fl oz of mineral oil as a carrier did not provide adequate control of storage molds and the damage with that treatment was as high as it was with the control (Figure 8). The treater auger and the application of MERTECT 340-F at the boot with a water carrier did provide a significant decrease of percent damaged kernels. It appears in this experiment that the use of 0.2 fl oz of mineral oil is not advisable with low temperature drying. This is probably because such low amounts of mineral oil do not provide enough carrier for the fungicide to give adequate coverage of individual kernels. It also seems that adequate coverage may not be as important with *Penicillium* spp. as it is with the *Aspergillus* spp. This could be due in part to the fact that MERTECT 340-F is extremely effective against *Penicillium* spp. but not as effective in the control of *Aspergillus* spp.

To Determine the Effectiveness of Iprodione--Experiment Three. Iprodione was identified in laboratory studies in 1986 as being a potential candidate for control of fungi during low temperature drying and storage. The compound was evaluated in a low temperature drying study at the rates of 0, 5, 10, and 20 ppm fungicide per grain weight adjusted to 15 percent moisture. In this experiment grain was harvested at 21 percent moisture and treatments were applied using the treater auger. Grain was allowed to dry in a similar fashion to the MERTECT 340-F low drying temperature experiment (Figure 9). Iprodione provided good control of *Penicillium* spp. with all rates being effective in control of that fungus (Figure 10). With respect to *Aspergillus* spp., here again, the compound provided good control with higher rates being more effective (Figure 11). The differences in percent damage (Figure 12) was very striking with this compound in that increasing rates provided more effective control of damage to kernels. Iprodione is a very good candidate in grain storage. Additional experiments have been started this year to evaluate it with even higher moistures at harvest and with high temperature drying.

CONCLUSIONS

The experiments done in 1986-87 support the contention that fungicides will fit into an integrated pest management system. They further demonstrate that fungicides are not a "cure-all" for bad management and must be used in conjunction with other methods of control. It should be reiterated that fungicides will provide control and suppress storage molds particularly when compared to untreated grain; however, it is important that the effectiveness of these compounds not be overstated.

Table 1. Moisture, Percent **Penicillium** *spp., Percent* **Aspergillus** *spp., and Percent Damage from Farm Bins Treated or Untreated with MERTECT 340-F*

Treatment	Sample date	Average moisture	Percent *Penicillium* spp.	Percent *Aspergillus*	Percent damage
		Farm Study One - Harvest Moisture 20 to 22 Percent			
Untreated	1-31-87	22.1	5.5	0.4	...
Treated 1		20.7	1.0	0	...
Treated 2		22.5	0.4	0	...
Untreated	3-11-87	17.2	39.5	0	...
Treated 1		19.2	0	0	...
Treated 2		20.5	0.4	0	...
Untreated	4-1-87	17.1	55.5	3	...
Treated 1		20.8	0	2	...
Treated 2		21.7	2.5	0	...
Untreated	5-28-87	13.3	29.0	10	8.6
Treated 1		15.3	3	2	2.5
Treated 2		14.7	17.0	2	7.5
Untreated	8-19-87	14.3	38	50	21.3
Treated 1		16.1	2	36	5.4
Treated 2		14.8	7	18	6.4
		Farm Study 2--Harvest Moisture 16.1 to 17.1 Percent			
Untreated	5-28-87	13.9	2.5	0	0.5
Treated		15.4	0	2.5	0.4
Untreated	7-23-87	13.6	0.5	9.5	0.6
Treated		14.6	0	0.4	0.4
		Farm Study 3--Harvest Moisture Unknown			
Untreated	5-29-87	17.2	46	91	26.2
Treated		16.4	16	20.5	1.4
		Farm Study 4--Harvest Moisture 17 to 18 Percent			
Untreated	4-4-87	18.2	2.5	0	2.3
Treated		15.9	2	0	2.6
Untreated	5-29-87	17.9	14.5	93.5	2.6
Treated		15.2	2	2.5	2.6
Untreated	7-17-87	15.4	28	92.0	92.8
Treated		15.5	0	4	3.1

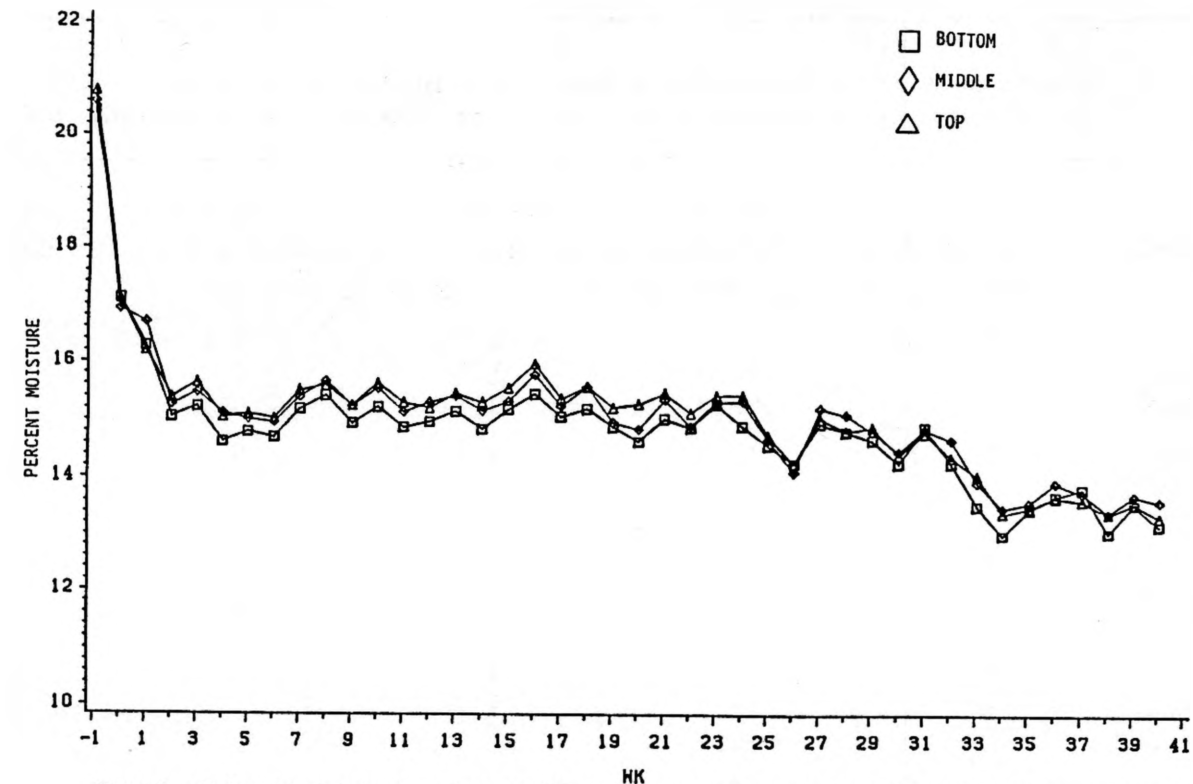

Figure 1. Grain moisture taken from three sampling levels in the bin averaged over two replicates in experiment 1. Week -1 is before drying.

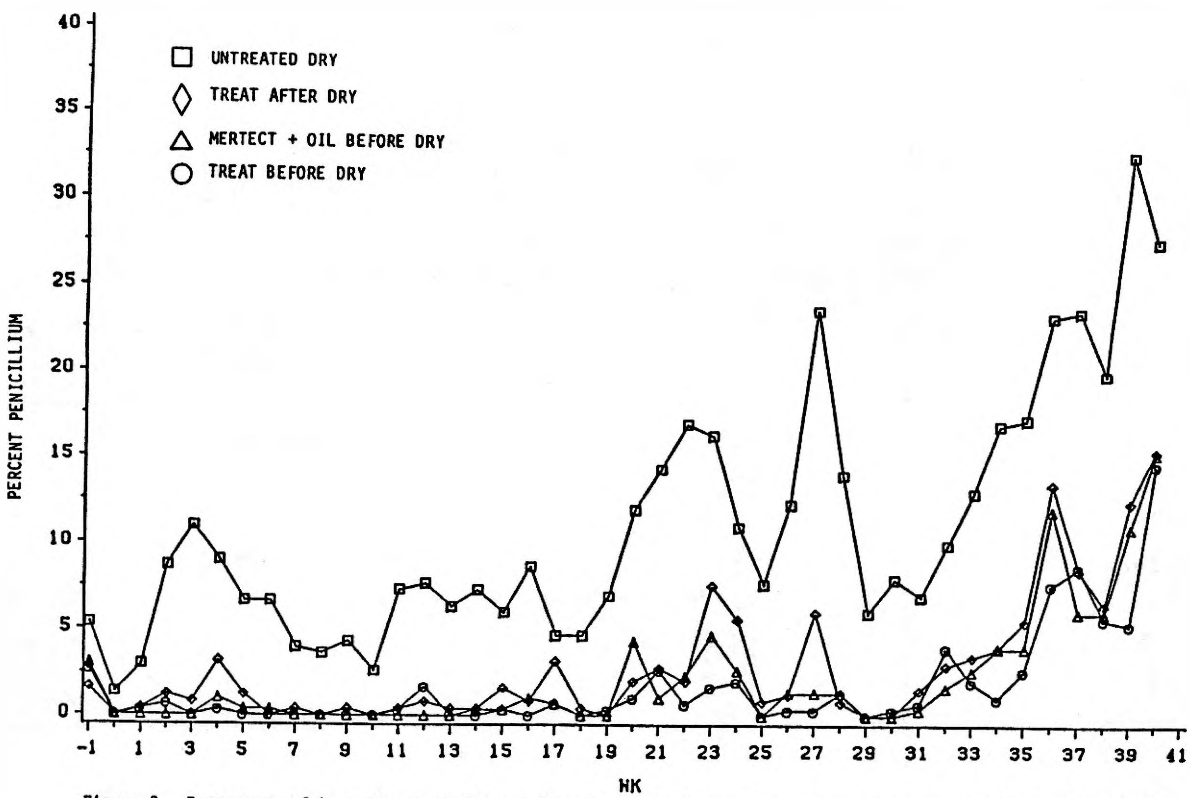

Figure 2. Percentage of kernels out of fifty infected with Penicillium spp averaged over three bin sampling levels and two replicates in experiment 1. Week -1 is pretreatment.

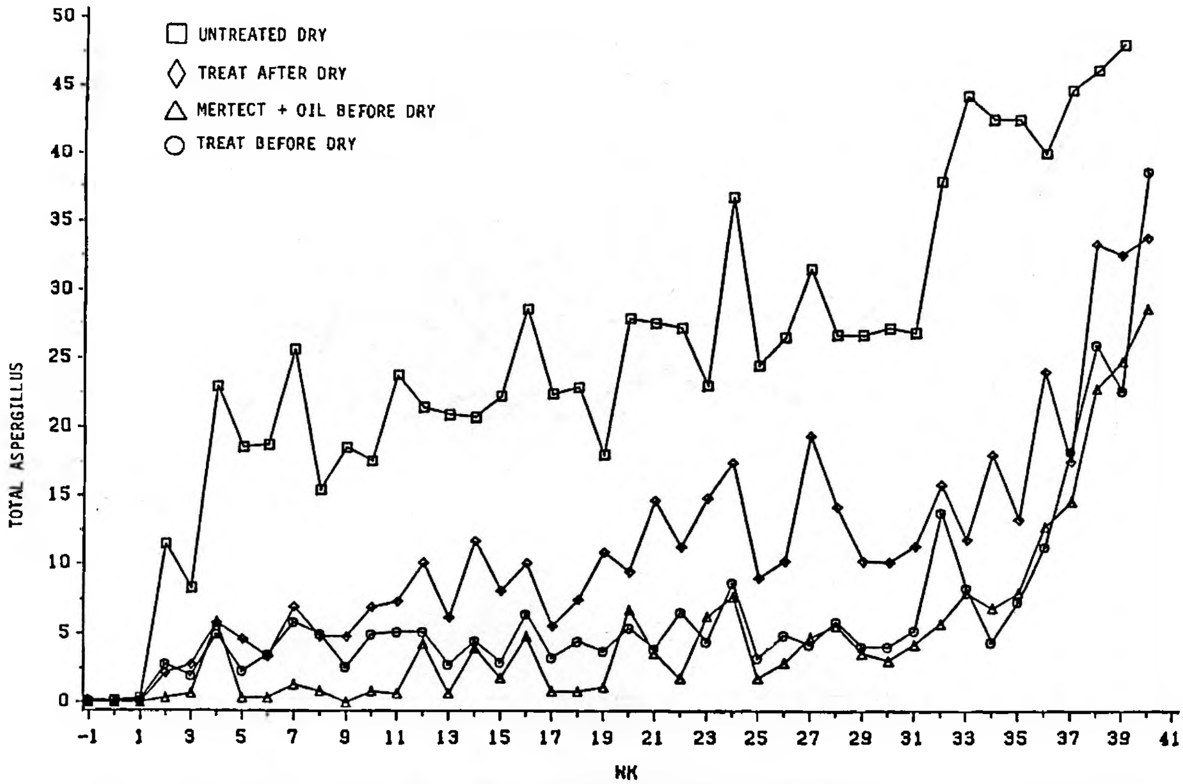

Figure 3. Total number of Aspergillus spp isolated from fifty kernels averaged over three bin sampling levels and two replicates in experiment 1. Week -1 is pretreatment.

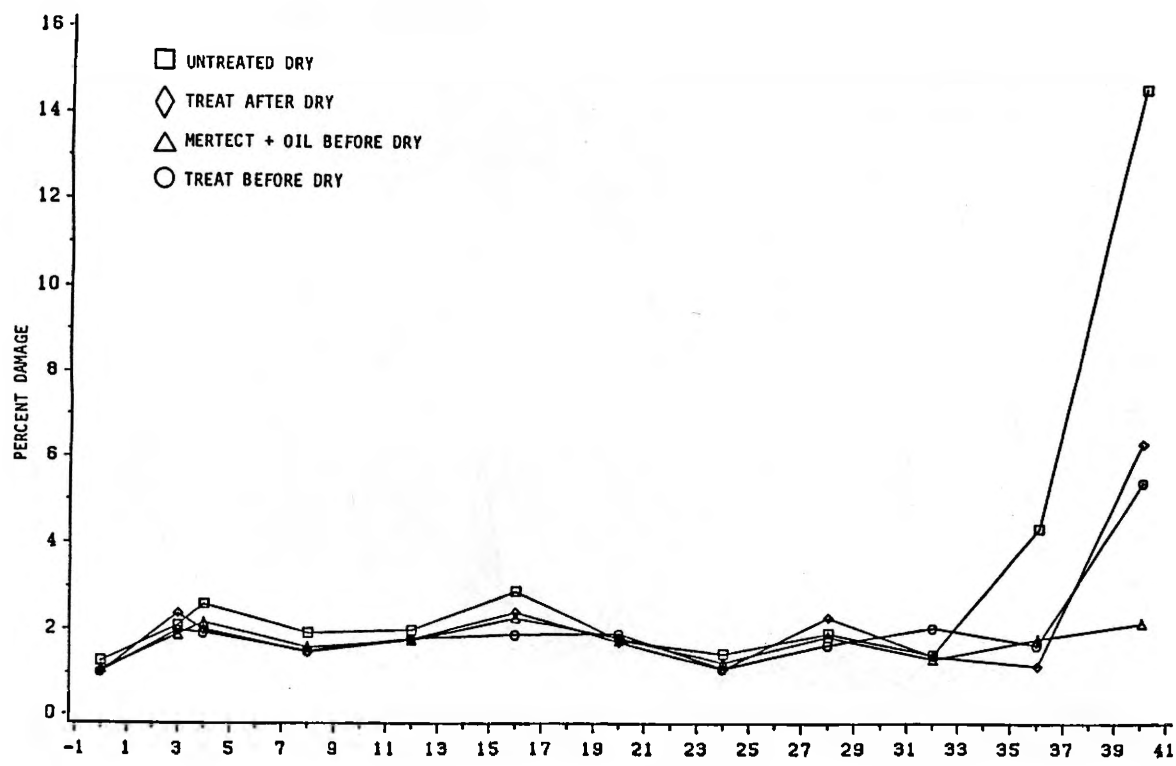

Figure 4. Percent damaged kernels as determined by federal grain inspection averaged over three bin sampling levels and two replicates in experiment 1.

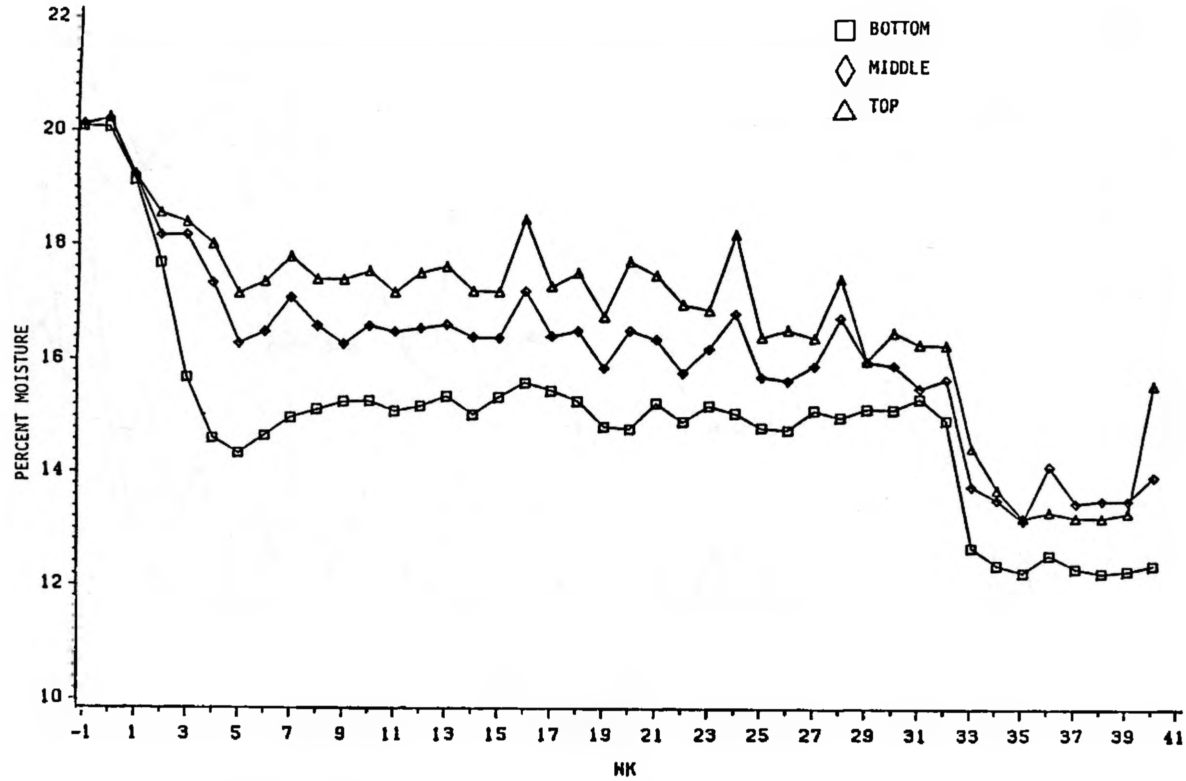

Figure 5. Grain moistures taken from three sampling levels in the bin averaged over two replicates in experiment 2. Week -1 is pretreatment.

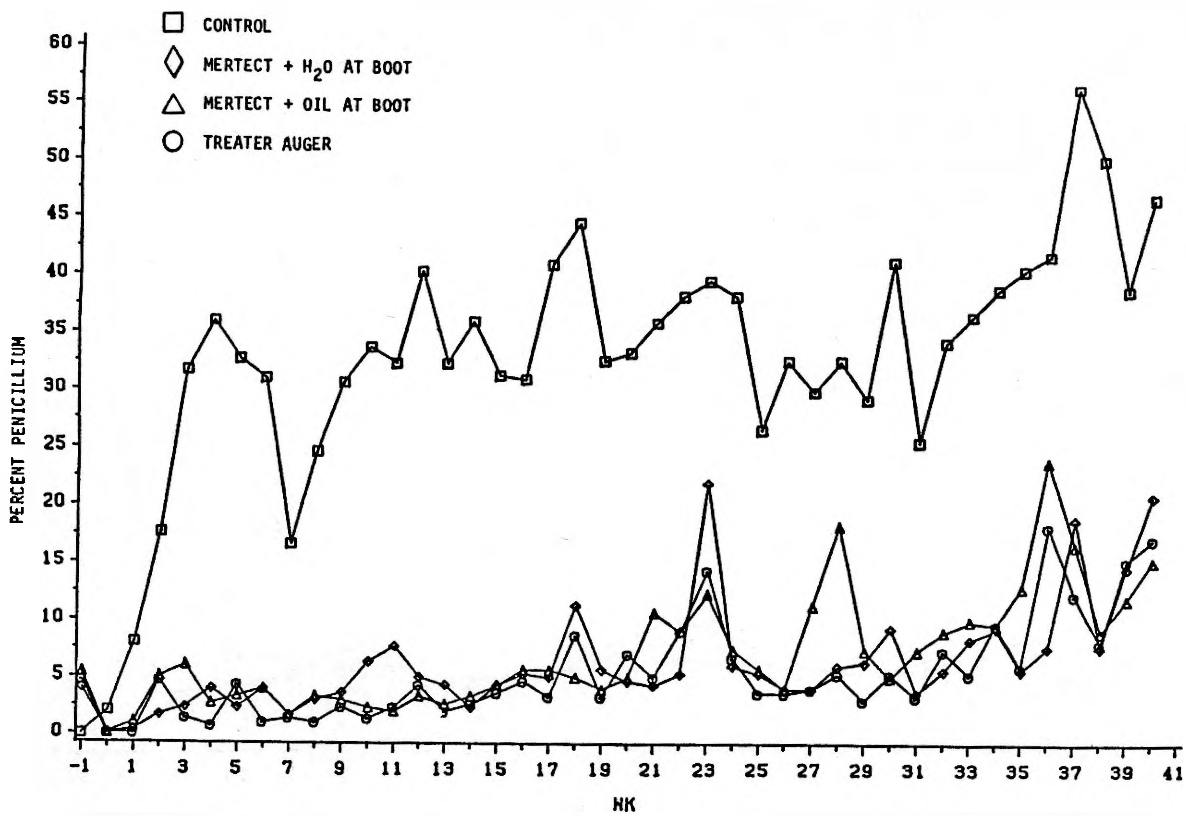

Figure 6. Percent of kernels out of fifty with Penicillium spp averaged over three bin sampling levels and two replicates in experiment 2. Week -1 is pretreatment.

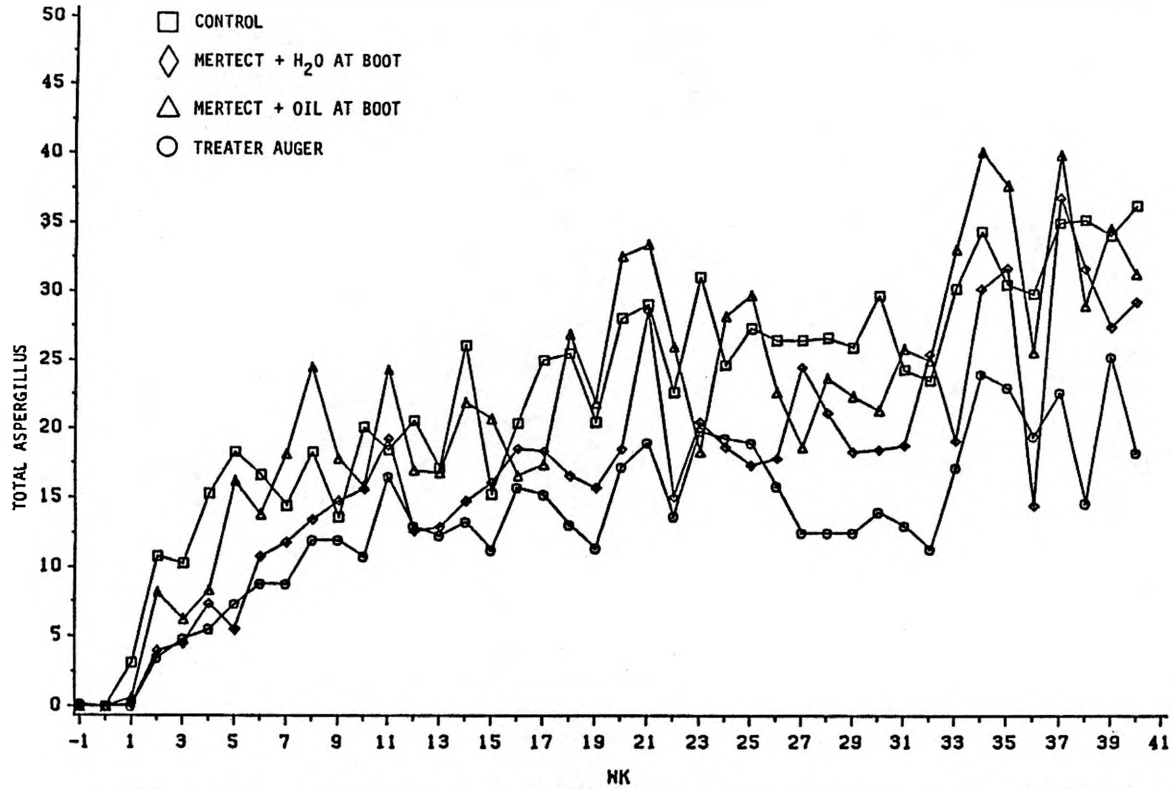

Figure 7. Total number of *Aspergillus spp* isolated from fifty kernels averaged over three bin sampling levels and two replicates in experiment 2. Week -1 is pretreatment.

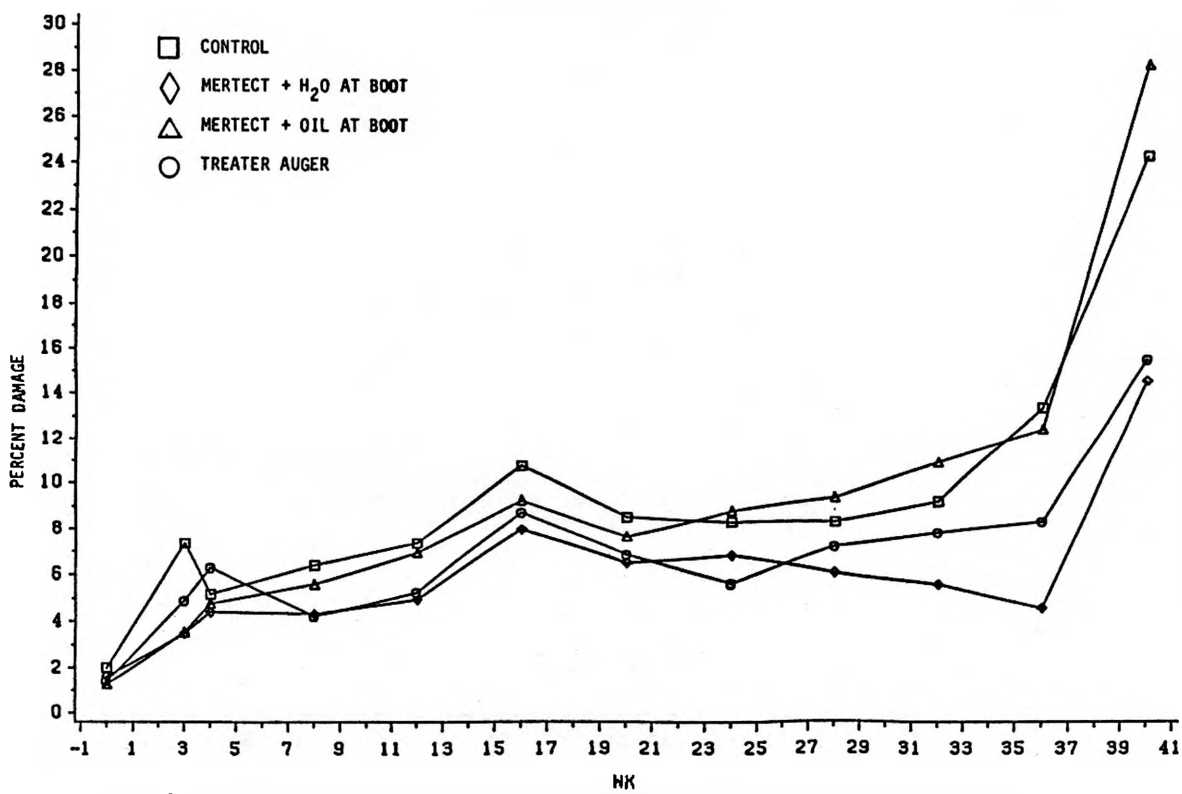

Figure 8. Percent damaged kernels as determined by federal grain inspection averaged over three bin sampling levels and two replicates in experiment 2.

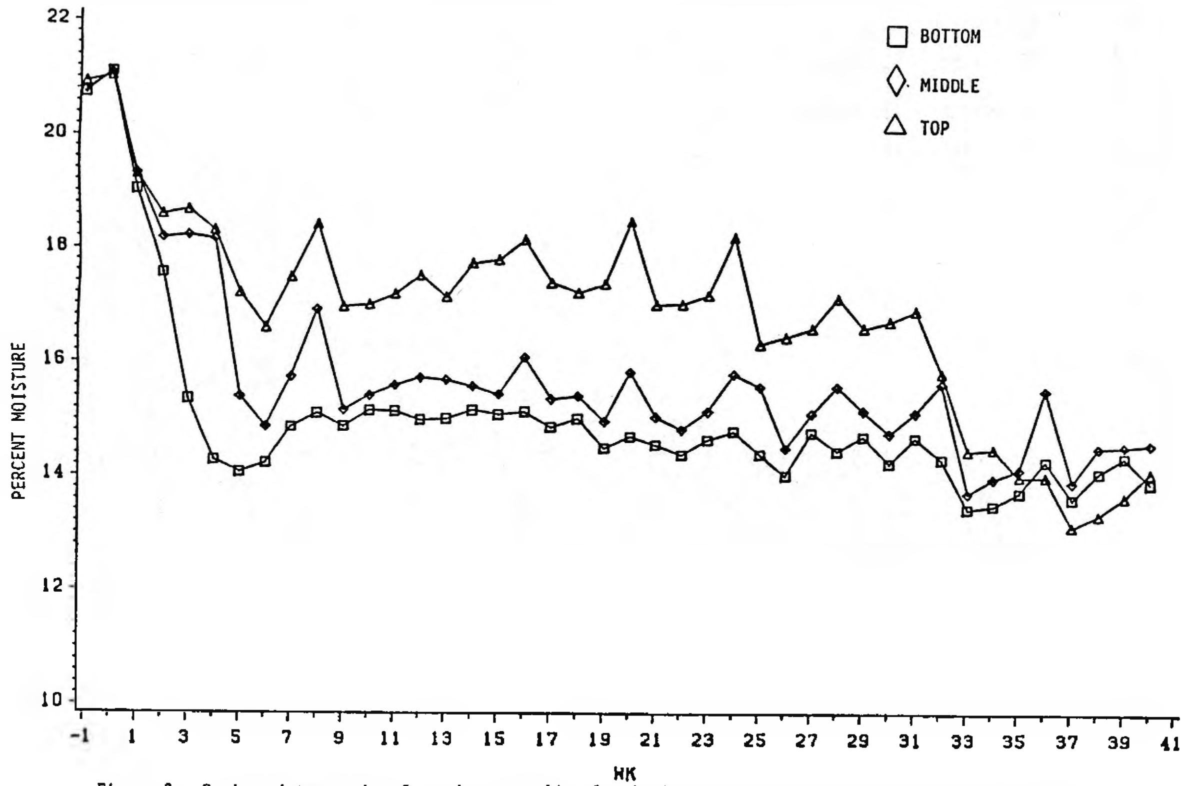

Figure 9. Grain moisture taken from three sampling levels in the bin averaged over two replicates in experiment 1. Week -1 is pretreatment.

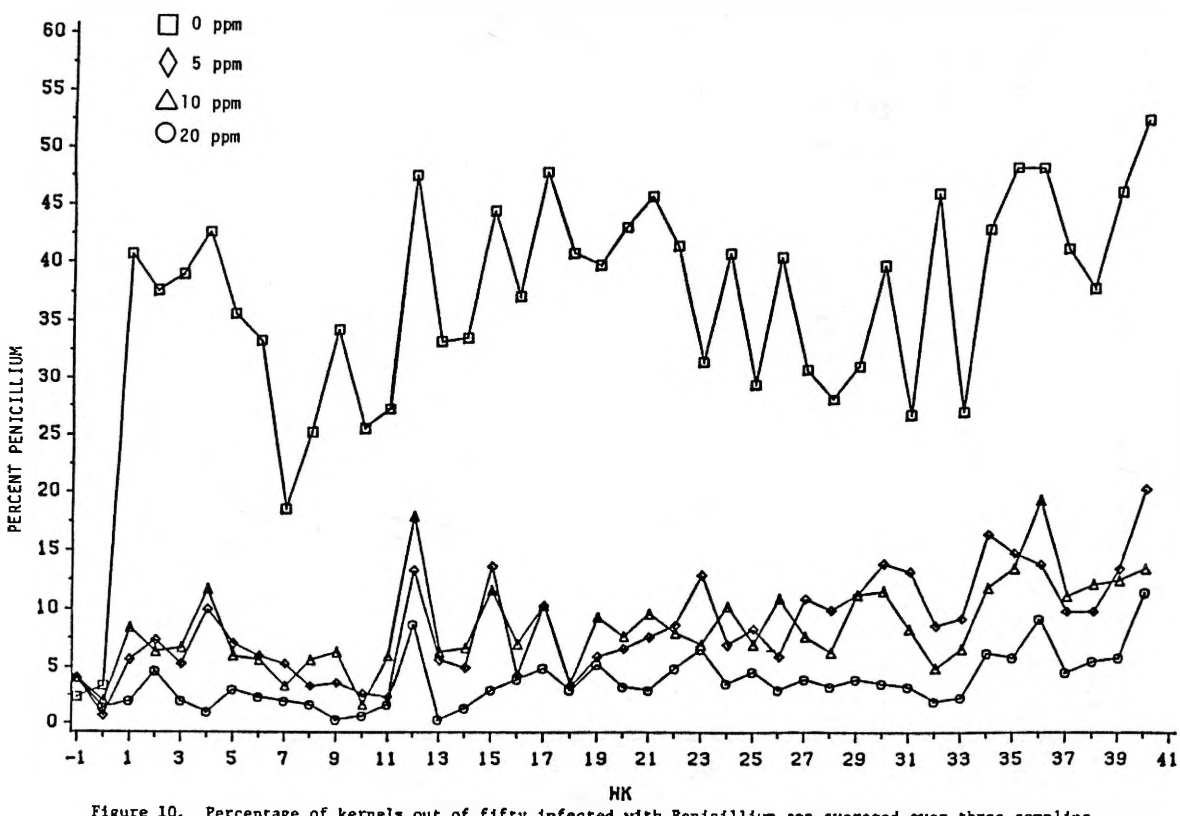

Figure 10. Percentage of kernels out of fifty infected with Penicillium spp averaged over three sampling levels and two replicates in experiment 3. Week -1 is pretreatment.

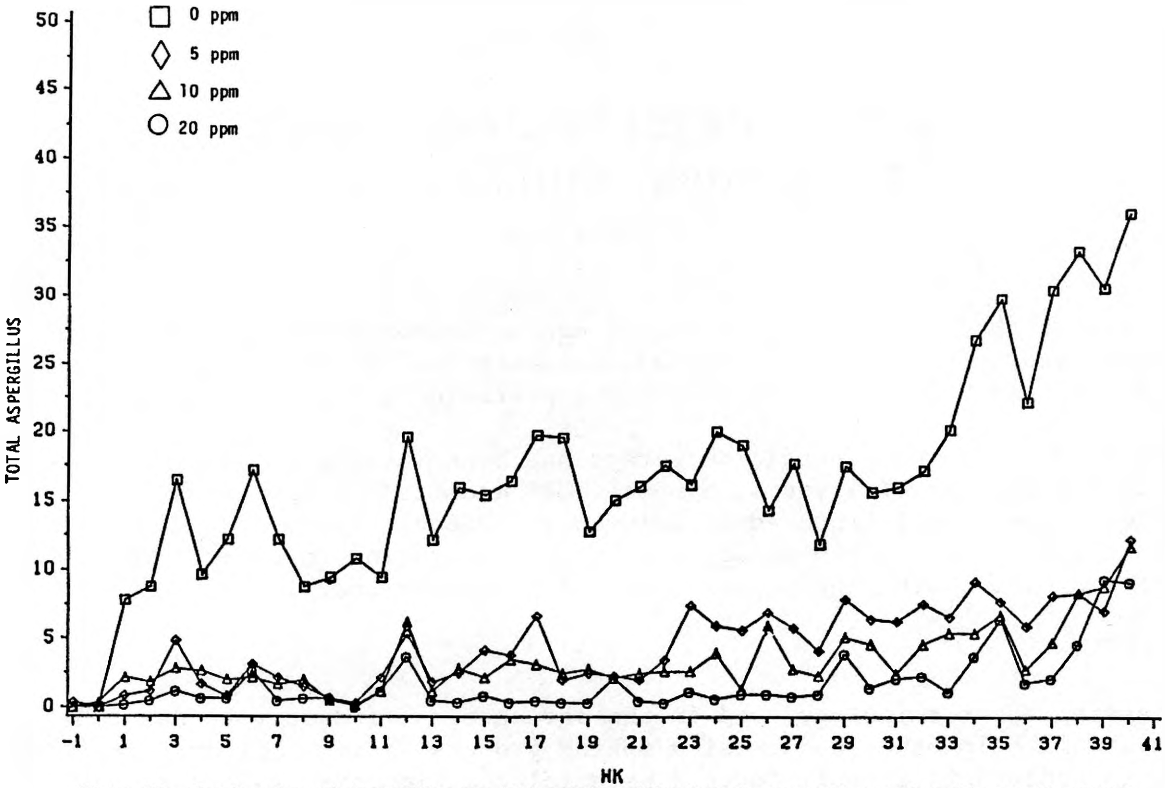

Figure 11. Total number of Aspergillus spp isolated from fifty kernels averaged over three bin sampling levels and two replicates in experiment 3. Week -1 is pretreatment.

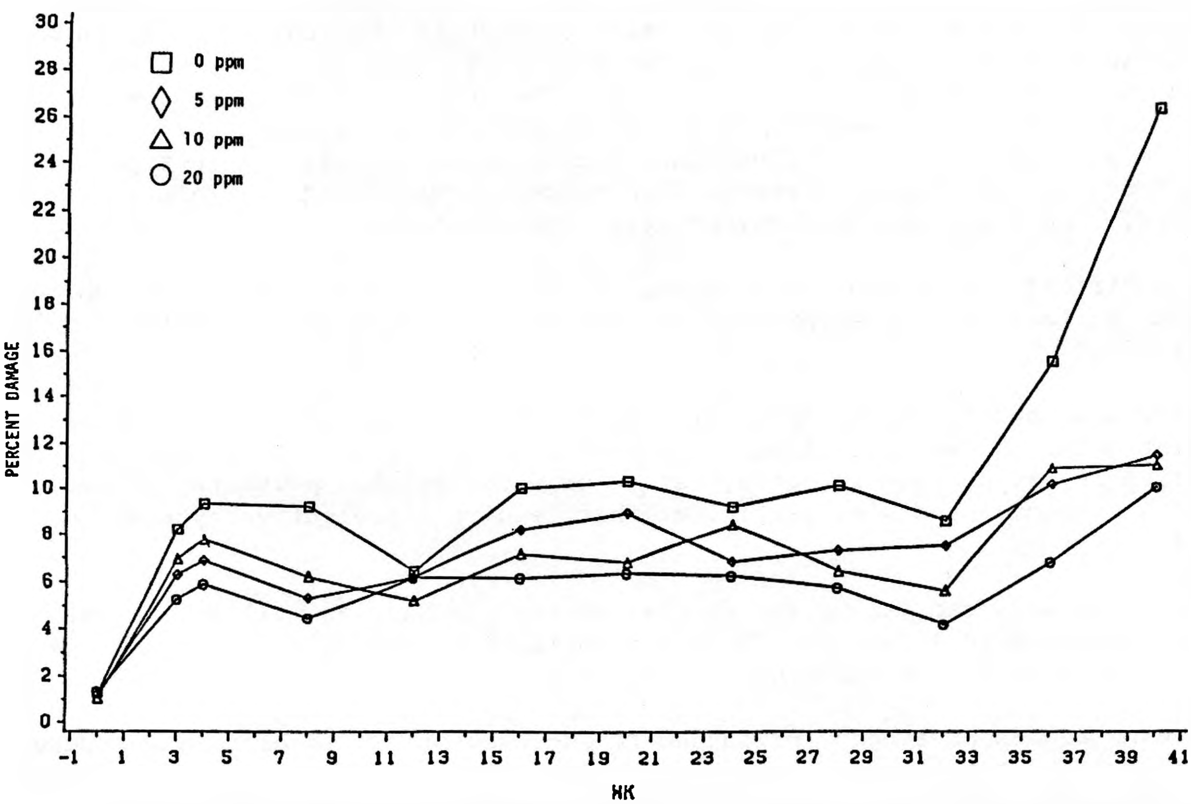

Figure 12. Percent damaged kernels as determined by federal grain inspection averaged over three bin sampling levels and two replicates in experiment 3.

Adjuvants for Postemergence Herbicides: Fundamentals

F. Koppatschek

Do you believe that pesticide performance can be improved through the use of adjuvants? Most users of pesticides would answer yes to that question; however, most users do not completely understand why pesticide performance is enhanced.

The use of adjuvants with pesticide sprays has been increasing at a dramatic rate. In the past several years, a number of "modified" crop oils and fertilizers have been introduced as adjuvants. Because these new adjuvants have specific activity on certain weeds, they can be confusing to users. This makes the decision of choosing the proper adjuvant a complex one.

TERMINOLOGY

Understanding the terminology used in the agrichemical industry to describe adjuvants will help make the decision-making process easier. First of all, the term "spray adjuvant" is defined as a material that improves some phase of spraying between initial spray mixing and final activity.

Adjuvants can be broken down into several categories based on their activity and performance. The first major group is surface-active agents or surfactants. Surface-active agents can be grouped based upon their chemical activity in water. Anionic surface-active agents are surfactants that, when placed in water, ionize into an anion and carry a negative charge. The negatively-charged group lends water solubility to a molecule. Cationic surface-active agents ionize into positively-charged ions or cations when placed in water. The third type of surfactants do not display a charge when placed in water and, therefore, are nonionic. These are the most common type of surfactants.

Spray modifiers are another major group of adjuvants. These adjuvants enhance activity by facilitating spray wetting, spreading, dispersing, solubilizing, and emulsifying.

Stickers are used to reduce spray droplet detachment from a surface through their adhesive action. Many materials are used for stickers, including vegetable oils, emulsifiable resins, mineral oils, waxes, or water-soluble polymers. Stickers are most commonly used with pesticides that require a protective type of activity.

Spreader-stickers decrease spray droplet surface tension as well as improve droplet adhesion to a surface. Most are nonionic in nature and are commonly used with wettable powder formulations.

Thickening agents have been introduced to increase spray viscosity and reduce droplet drift. Antifoaming agents are used to eliminate foam in spray tanks. These agents most commonly contain silicones.

HOW THEY WORK

Most surfactants work by concentrating on the surface of the liquid in which they are dissolved. There are two components that make up a surfactant molecule and account for its activity. One segment resembles a "head" portion; it is nonpolar and water-insoluble. The other segment resembles a "tail" and is polar and soluble in water. The surfactant molecule interacts with a spray solution by having the "head" portion, which is repelled by water, move to the surface of the droplet. The "tail" portion, which is attracted to water, remains in the spray droplet. When the surfactant molecules in the spray droplet are arranged in this fashion, the surfactant reduces the surface tension normally established by polar water molecules being held together tightly at the surface. Hence, small water droplets that usually form beads and may roll off a surface, spread out, making more thorough contact and improving activity.

RECENT DEVELOPMENTS

Fertilizer additives have been receiving a great deal of interest as adjuvants for postemergence herbicides. They have gained acceptance by farmers due to their effectiveness, availability, and price. Fertilizers such as 28 percent nitrogen solution, 10-34-0, and ammonium sulfate have been found to have activity with postemergence herbicides on velvetleaf, cocklebur, and giant ragweed. Weed species that have a waxy cuticle (for example, lambsquarters) require the use of traditional adjuvants, such as crop oil concentrate, to achieve maximum control.

The reason for this specific selectivity among species is still not clear. Preliminary research indicates that possible improvements in herbicide uptake are occurring when 28 percent nitrogen solution is used with Blazer or Basagran on velvetleaf. Research conducted at the University of Illinois suggests that 28 percent nitrogen solution reduces surface tension at the same rate as crop oil concentrate or nonionic surfactant X-77. However, 10-34-0 and ammonium sulfate failed to reduce surface tension.

Dash is a new "modified" crop oil that was released in 1987 by BASF corporation. It has attracted attention due to its ability to reduce antagonism between postemergence grass and broadleaf herbicides and its overall effectiveness as a surfactant. According to BASF sources, Dash has the ability to enhance herbicide uptake but does not greatly enhance translocation. Dash is more expensive than crop oil concentrate but may offer advantages that outweigh the additional cost.

Expect to see even more changes in the adjuvant market in the future. The area of adjuvants has not been heavily researched and "new and improved" versions of adjuvants will likely be reaching the marketplace in the upcoming years. The issue of choosing the proper adjuvant will no doubt become more confusing, but selecting the proper adjuvant can have tremendous payoffs through optimum pesticide performance.

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Adjuvants for Postemergence Herbicides: Field Results

R. Fielding

During the past few years, additives have been studied extensively by universities, industry, and innovative farmers. Although the large number of possible combinations of surfactants, crop oils, and fertilizer solutions has created many questions about which additives are the best, there are no simple answers. When selecting an additive, the target weeds, herbicide, and environmental conditions should be considered.

The use of fertilizer solutions with Basagran and Blazer has been studied quite extensively. The merits of using nitrogen solutions (28 percent nitrogen, 10-34-0, 32 percent nitrogen, or ammonium sulfate) with Basagran have been recognized in the past few years. The main advantage of using nitrogen solutions is increased velvetleaf control. University of Illinois studies have shown that when fertilizer solutions are used instead of crop oil concentrate (COC), control of velvetleaf by Basagran is significantly better and control of velvetleaf by Blazer can be greatly improved.

This year the Basagran label will recommend using 1 gallon of 28 percent nitrogen solution in place of COC for most applications. COC could be an advantage when common lambsquarters is one of the target weeds. When both velvetleaf and common lambsquarters are target weeds, some farmers have tried using both COC and 28 percent nitrogen in the same tank mix but at reduced rates (1/2 pint of COC and 1/2 gallon of 28 percent nitrogen). Although this is not a labeled tank mix, research is being conducted by BASF to determine if this is practical.

Last year a new additive was introduced into the market. This additive, called Dash, can be used when Basagran is tank mixed with Poast to reduce or eliminate the usual antagonism of Poast by Basagran. Studies by BASF indicate that using Dash at the rate of 1 quart per acre eliminates much of the antagonism, and using 1 quart per acre of Dash plus 1 gallon of 28 percent nitrogen eliminates essentially all of the antagonism; therefore, with this tank mix there may be little need to increase the rate of Poast. Dash also increases the activity of Blazer but does not increase the activity of Basagran.

The addition of nitrogen solutions to some newer herbicides has also resulted in improved control of certain weeds. With Classic herbicide, the best results are obtained by using 28 percent nitrogen plus a surfactant or COC. In studies conducted at the University of Illinois over the past two years, 1 gallon per acre of 28 percent nitrogen added to a tank mix of Classic and X-77 surfactant resulted in the average level of velvetleaf control being significantly higher. This year the Classic label will require the use of 1 gallon of a nitrogen solution (28 percent nitrogen, 32 percent nitrogen, or 10-34-0) plus either a nonionic surfactant or COC. The use of COC will probably result in more injury to the soybeans, but control of some weeds such as morningglory may be improved by its addition.

Another postemergence broadleaf soybean herbicide that is similar to Classic will be tested under an experimental use permit this year and may be available in 1989. This herbicide, to be named Pinnacle, will be used with a nonionic surfactant or with the optional addition of a nitrogen solution to improve velvetleaf control. One of the main advantages of this herbicide is that it can control common lambsquarters. However, in order to do this, a nonionic surfactant must be used even if a nitrogen solution is used.

The use of fertilizer additives with some postemergence grass herbicides is also being studied, but the results are quite variable. These studies involve testing different additives when the herbicide rates are reduced to one-half to one-fourth of the normal use rates. The herbicides being studied are Assure, a new postemergence grass herbicide, and Poast. With these herbicides, a slight improvement may be seen in giant foxtail and volunteer corn control by using 28 percent nitrogen along with COC.

Although a large amount of effort has been put into studying additives, many questions remain unanswered. For example, from year to year and from one location to another, the effect of adding nitrogen solutions to herbicides has varied. It seems that the effectiveness of adding a fertilizer solution to a tank mix is dependent upon the interaction of the environmental conditions, the weed species, and the type of herbicide. What we do know is that, in many situations, the addition of fertilizer solutions to a tank mix can significantly improve the control of certain weeds at very little additional expense.

Herbicides on the Horizon

M. McGlamery

NEW ACTIVE INGREDIENTS IN 1987

Four new herbicides, Whip, Cobra, Reflex, and Harmony were introduced in 1987. These are relatives of existing herbicides. Whip (fenoxaprop) is a postemergence grass herbicide related to Fusilade (fluazifop). Cobra (lactofen) and Reflex (fomesafen) are diphenylether herbicides related to Blazer or Tackle (acifluorfen). Harmony (DPX-M6316) is a sulfonylurea herbicide related to Classic (chlorimuron).

WHIP 1.5 EC is used for postemergence grass control in soybeans. The rate is 0.8 pint per acre for giant foxtail (2 to 3 inches tall) or volunteer corn (10 to 16 inches tall). A rate of 1.2 pints per acre is used for 3- to 6-inch tall fall panicum, barnyardgrass, or wirestem muhly and 10- to 20-inch tall johnsongrass. A second application may be required for adequate rhizome johnsongrass control. The addition of crop oil concentrate (COC) is required for control of wirestem muhly, giant foxtail, fall panicum, yellow foxtail, and crabgrass. This is optional for the control of shattercane or johnsongrass seedlings and should not be used for rhizome johnsongrass. Rainfall within one hour of application may reduce grass control. Whip can be tank-mixed or sequenced with Reflex (see Reflex label).

COBRA 2 EC is applied at 10.5 to 12.5 fluid ounces per acre with or without COC for the postemergence control of broadleaf weeds in soybeans. Apply when weeds are small, for example, before the 4- to 6-leaf stage. Use the higher rate with COC when the weeds approach the maximum leaf stage (see label). Weeds controlled include cocklebur, jimsonweed, pigweed, common ragweed, and black nightshade. Annual morningglory and velvetleaf control can be enhanced by using the higher rate with COC on weeds with four leaves or less.

Cobra is a contact herbicide. The higher rate plus COC will intensify soybean leaf burn. The crop usually recovers in two to three weeks after application. Cobra requires a rain-free period of 30 minutes after application. Combinations with other broadleaf and grass herbicides are pending approval.

REFLEX 2 LC is used for postemergence broadleaf weed control in soybeans. The rate is 0.75 to 1 pint per acre (north of Interstate 70) or 1.25 pints per acre (south of Interstate 70). Use a minimum spray volume of 10 gallons per acre and add either COC at 1 percent by volume (1 quart per 25 gallons) or nonionic surfactant at 0.25 to 0.50 percent by volume. Reflex controls pigweed, black nightshade, jimsonweed, smartweed, and common ragweed up to the 4-leaf stage. Reflex can be tank-mixed with Basagran at 1 to 2 pints per acre to improve velvetleaf and giant ragweed control or with 2 to 3 fluid ounces of Butyrac 200 to improve control of annual morningglory, giant ragweed, and cocklebur. Reflex can be tank-mixed with Fusilade or sequentially-applied after Fusilade. Do not apply Reflex if rain is expected within four hours of application or more than three weeks after soybean emergence. See the current label concerning recropping restrictions.

HARMONY 75 DF had an Illinois Section 18 Emergency Use Label in 1987 for wild garlic control in wheat. Illinois will apply for a Section 18 label for 1988 if a federal registration is not granted. Harmony rates are 1/3 to 2/3 ounce per acre. A surfactant is to be used when applied with water but not with liquid fertilizers as the carrier. Doublecrop soybeans may be grown after Harmony use on wheat. Do not underseed clover or alfalfa in the wheat. Harmony plus Express will be sold under the tradename of Matrix in the small grain market in 1989.

CROSSBOW (triclopyr plus 2,4-D) was registered in 1987 for postemergence control of broadleaf weeds and brush in pasture. It contains the active ingredient, triclopyr, found in Garlon plus 2,4-D. Garlon controls several brush species in pasture so it will help replace the loss of 2,4-T and silvex. Tordon's registration for use in pasture will probably be discontinued.

NEW ACTIVE INGREDIENTS ON THE HORIZON

ASSURE (quizalifop) may be registered in 1988 for postemergence grass control in soybeans. Assure 0.8 EC was tested at 5 to 10 fluid ounces per acre for giant foxtail, shattercane, or volunteer corn, and 10 to 15 fluid ounces per acre for other annual grasses including volunteer cereals. Crop oil concentrate should be used at 1 quart per acre for ground application or 1 pint per acre for aerial application, or a nonionic surfactant at 0.2 to 0.5 percent by volume may be used. Johnsongrass and quackgrass control may require a second application if regrowth occurs. Use a minimum of 15 gallons of water per acre for ground application or 5 gallons of water per acre for aerial application. Do not apply if rain is expected within 3 hours. The fully registered label and formulation may differ from the experimental one, so read and follow the registered label.

CINCH (cinmethylin) is a soil-applied grass herbicide being developed by DuPont Chemical for use in soybeans. Cinch 7 EC was tested at 1.0 to 1.5 pounds active ingredient per acre. It has the potential for being used preplant incorporated or preemergence. Incorporation may decrease soybean tolerance. Registration will probably occur in 1989.

PURSUIT (imazethapyr), a relative of Scepter, is being developed by American Cyanamid. Pursuit can be used as a soil-applied or a postemergence herbicide. Pursuit has a higher specific activity (less needed per acre) and better corn tolerance than Scepter, so there is less likelihood of carryover injury to corn. However, sorghum is more susceptible to Pursuit than it is to Scepter.

Pursuit 2 EC is being tested at rates of 0.06 to 0.09 pounds (1 to 1.5 ounces) active ingredient per acre. Pursuit controls velvetleaf and foxtail better than Scepter, but is weaker on cocklebur when soil-applied. Used postemergence with a surfactant, Pursuit controls cocklebur, velvetleaf, and pigweed and may provide fair to good control of giant foxtail. Pursuit had an experimental use permit in 1987. Full registration is targeted for 1989.

PINNACLE (DPX-M6316) will be developed as a postemergence broadleaf herbicide by DuPont for use in soybeans. It contains the same active ingredient as Harmony.

It controls lambsquarters better than Classic, so it will probably be developed in combination with Classic.

VERDICT (haloxyfop) has been under development by Dow Chemical for several years as a postemergence grass herbicide for soybeans. The EPA has stalled its registration because of toxicity concerns, but Dow believes that it will be registered in 1989. It is currently registered and used in several foreign countries.

BAS 517 (cycloxydim) is being developed by BASF as a postemergence grass herbicide for soybeans. It is related to Poast and probably will not be registered until 1990 when BASF's Poast license from Nippon Soda expires.

SELECT (clethodim) is being developed by Chevron as a postemergence grass herbicide for soybeans. It is related to Poast. Its continued development will depend on several factors.

IGNITE (glufosinate) is being developed by Hoescht-Roussel as a knockdown herbicide similar to Roundup, (glyphosate). It controls some broadleaf weeds better than Roundup but is not as good controlling volunteer wheat.

TOUCHDOWN (sulfosinate) was being developed by Stauffer (now ICI) as a knockdown herbicide similar to Roundup (glyphosate). It controls the same weeds as Roundup. Patent infringement suits have been in the courts for several years. Continued development will depend on the outcome of litigation and the current interest of ICI, who now owns the rights to the product.

LONTREL (clopyralid) and STARANE (fluroxypyr) are being developed by Dow as postemergence broadleaf herbicides. They are related to Garlon (triclopyr) and Tordon (picloram) but have slightly different selectivity and soil persistence. They are being tested in corn, sorghum, small grains, and pasture.

NEW FORMULATED (PREMIX) COMBINATIONS ON THE HORIZON

A number of formulated premix combinations appeared in 1987. Prozine (pendimethalin plus atrazine) and Laddox (bentazon plus atrazine) were registered for corn. Squadron (pendimethalin plus imazaquin), Commence (trifluralin plus clomazone), Preview (metribuzin plus chlorimuron), Lorox Plus (linuron plus chlorimuron), and Salute (trifluralin plus metribuzin) were registered in 1987 for use in soybeans.

COLONEL (paraquat plus atrazine) will be marketed by ICI in 1988 for knockdown use in minimum-tillage corn and sorghum. The amount of atrazine improves the knockdown ability of paraquat but is not enough for residual control. Colonel can be mixed with most preemergence herbicides for corn or sorghum. Colonel requires the use of a nonionic surfactant to the spray solution. Colonel is a restricted-use pesticide (certified applicator).

TOPGUN (paraquat plus simazine) is to be marketed by ICI in 1988 for use in no-till corn and apple, pear, or peach orchards. It contains 0.8 pounds of paraquat plus 3.2 pounds of simazine per gallon. The rate per acre is 5 to 7.5 pints in corn and 4 to 10 pints in orchards. It can be applied with Lasso, Dual, or Prowl in corn to improve residual grass control. Topgun will require the use of a nonionic surfactant to improve knockdown control. It is a restricted-use pesticide.

PRELUDE (parquat plus linuron plus metolachlor) is being marketed by ICI for use in minimum-tillage soybeans and sorghum (must have Concep II seed treatment). The linuron improves the knockdown spectrum of paraquat but is not enough for residual control. The metolachlor (Dual) provides residual grass control. Prelude can be used in combination with other residual broadleaf preemergence herbicides. Prelude requires the use of a nonionic surfactant. It is a restricted-use pesticide.

PARTNER (alachlor plus imazaquin) is being developed by Monsanto for incorporated or preemergence weed control in soybeans. Partner will probably be a 16:1 ratio of the active ingredients in Lasso and Scepter. The likely use rate will provide 2 pounds of alachlor and 0.125 pound of imazaquin (2 quarts of Lasso 4 EC and 2/3 pint of Scepter). Continued development will depend upon cooperation between American Cyanamid and Monsanto.

TRISCEPT (trifluralin plus imazaquin) may be developed by American Cyanamid for preplant incorporated use in soybeans. It contains the active ingredients in Treflan and Scepter. The ratio and rates are not known.

STORM (bentazon plus acifluorfen) was sold in 1987 in states south of Illinois and may be sold in southern Illinois in 1988. It is a 2:1 mixture of the active ingredients or a 1:1 mix of Basagran 4L and Blazer 2L. Another ratio was developed for northern states with the proposed tradename of Doble. Will these or similar premixes be registered in Illinois for 1988?

TORNADO (fomesafen plus fluazifop) is a formulated combination of the active ingredients in Reflex (fomesafen) and Fusilade 2000 (fluazifop). Tornado is to be applied postemergence in soybeans to actively growing weeds at a rate of 1 quart per acre in 10 to 40 gallons of water. Always add either a nonionic surfactant at 0.25 percent to 0.5 percent or a COC at 1.0 percent of the final spray volume. Restrictions on the Reflex and Fusilade label will be included for the premix combination.

ACCENT (DPX-M6316 plus atrazine) will be developed as a postemergence broadleaf herbicide for corn. The premix contains the active ingredient in Harmony (soon to be Pinnacle) plus atrazine.

LARIAT (alachlor plus atrazine) is a new formulation and name for Lasso/atrazine premix. It will be a 2.5:1.5 ratio of products containing 4 pounds of active ingredient equivalent to 2.5 quarts of Lasso 4E and 1.5 quarts of atrazine 4L per gallon. The use rate for preplant incorporation and preemergence use will be 1.5 to 4.5 quarts per acre depending upon soil texture and organic matter content. The reason for the Lariat formulation is that it has better tank-mix compatability with liquid fertilizers.